ECONOMIC IMPLICATIONS OF A UNITED STATES SUPERSONIC TRANSPORT AIRCRAFT UPON AIRPORTS AND ENROUTE SUPPORT SERVICES

Volume III

Enroute Support Services

PRC R-890

31 December 1966

Prepared for

Economics Staff

Office of Supersonic Transport Development

Federal Aviation Agency

PLANNING RESEARCH CORPORATION

LOS ANGELES, CALIFORNIA   WASHINGTON, D.C.

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This study has been prepared by the Planning Research Corporation for the Office of Supersonic Transport Development, Federal Aviation Agency, under Contract No. FA-SS-66-15. Contents of this study reflect the views of the contractor who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policies of the FAA. This study does not constitute a standard, specification or regulation.

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CAPSULE REVIEW OF THE ECONOMIC ANALYSIS OF SST IMPACT UPON AIRPORTS AND ENROUTE SUPPORT SERVICES

The unique public costs to be incurred in airports and enroute support services as a result of the introduction of an SST are minimal; i.e., — zero to $19 million.

Airports and Terminals (25 existing, potential SST)	zero to $19 million
Enroute Support Services (Airways, Navigation, Communications, Meteorology and Radiation)	zero

The public costs which would be incurred at existing, potential SST airports as a direct result of the introduction of succeeding aircraft types into scheduled airline service through 1975 were estimated to be $33 million for the correction of pavement deficiencies at 25 major hubs from the present time through the introduction of the SST in 1974-5. The costs to government, Federal and local, for pavement improvement programs at the potential SST airports to adequately support the larger commercial airliners through the DC-8-63 would approximate $14 million. Airport modifications imposed by the SST would cost an additional $19 million. These potential improvements at airports represent public investment only and do not include airline and concessioner-financed facilities or airport modifications which are built with locally derived funding. Airport costs attributable to the SST are for modification programs only. New airport construction costs were not assessed against particular aircraft types because the designs of new hub airports programmed and under construction are based upon the total integrated requirements of civil aeronautics projected to 1990. Most hubs which serve traffic generating centers are today obsolescent—their designs having been based upon pre-jet, pre large-capacity aircraft criteria, thinking, and concepts. Limited with regard to size, location, and

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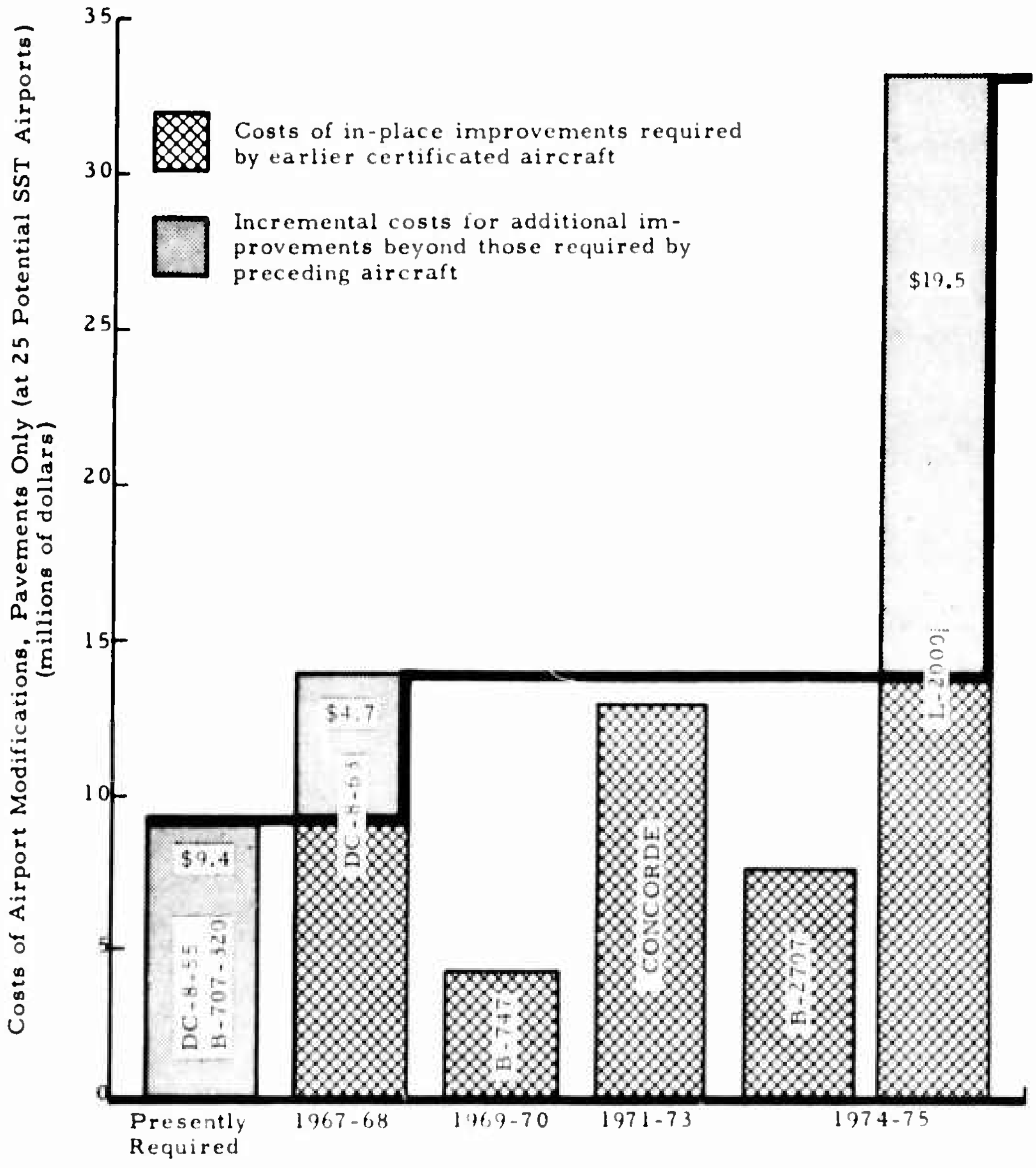
topography, the busier existing hubs are constrained within an economics viability envelope which in turn depends upon community support for its integrity. It is difficult, in fact unrealistic, to foresee extensive modification and expansion of existing hubs beyond 1975. Only the construction of wholly new commercial airport complexes to supplement or replace the existing overtaxed, inextensible airports can provide for continuing, orderly growth of air commerce into the supersonic and V/STOL era.

While the SST will require a $19 million investment to strengthen pavements at airports it will initially serve, the total airport situation within the United States during the next four years will require a minimum investment of $2 billion. The air traffic (both passenger and cargo) preference increase of the mid-1960's should continue unabated into the 1970's. Airports—without the SST as a consideration—are today a problem of national scope.

Examination of the adequacy of enroute support services disclosed that there are no identifiable costs which can be considered unique to the SST, or in fact, unique to any aircraft type. The trend in airways, navigation, and communications systems design is to provide independent, accurate, and reliable avionics systems within the aircraft and to lessen the dependency upon externally oriented systems. The expansion and improvement of air commerce support activities to keep pace with traffic growth are evolutionary technological advances which increase civil aeronautics capabilities. Meteorological and radiation systems thought to be required for safe and efficient flight of the Concorde and SST are already planned and programmed to be in operation prior to commercial flights by the SST. Any unique requirements which might evolve out of future studies in these areas (for example, the need for clear air turbulence detection systems) would probably result in airborne systems to satisfy these requirements rather than in additional external enroute support services. Such airborne systems would become integral parts of the aircraft and thus become an airline expense. It may therefore be stated that the SST will not require unique expenditures for enroute support services.

Environmental enroute support systems requirements are essentially the same for both the Concorde and the SST. Utilizing a cost allocation technique whereby the first aircraft type to need a service is assigned the entire investment (as well as) operation and maintenance costs during the periods of exclusive benefit, the Concorde would be allocated these costs since it is scheduled for commercial airline service approximately three years prior to the SST.

Exhibit i presents the expenses identifiable only with the field of aviation and which would be financed by Federal, state, or local funds. This chart allocates these costs by aircraft type according to forecast entry into commercial service.



Note: Highest point of vertical bar indicates total cost of pavements (runway and taxiway strengthening and fillet enlargements) for an airliner if that aircraft had entered commercial service during 1966.

EXHIBIT i - INCREMENTAL PAVEMENT IMPROVEMENT (PUBLIC) COSTS AT 25 POTENTIAL SST AIRPORTS

ABSTRACT

This volume of the study to define the economic implications of a United States supersonic transport aircraft (SST) describes the major costs associated with necessary modifications to enroute support services. The degree of responsiveness of existing capabilities to the needs of the larger, faster, higher-flying aircraft which will join free world airfleets by 1975 is examined in relation to airways, navigation and communications, meteorology, and radiation. Proposed and evolutionary successor systems are identified. The nature and extent of improvements planned and the costs of their development, fabrication and installation are presented and discussed as related to the needs of the four advanced high-capacity aircraft types:

- stretched subsonics (DC-8-63)
- high-capacity subsonics (B-747)
- Concorde
- United States SST

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I. INTRODUCTION

As a part of the total study effort by Planning Research Corporation, Volume III examines the economic implications to free world governmental authorities of improvements and modifications in three distinct areas where the Government may provide support to the SST. These areas are:

- Airways, Navigation, and Communications
- Meteorology
- Radiation Detection and Measurement

Each of these three areas is examined to determine the nature and associated costs of facility modifications and improved support capabilities which may be required by the existing subsonic jet family, as well as by the improved passenger transport aircraft which may join or succeed them. This approach is necessary so that costs of each facility and associated support equipments may be allocated to the aircraft type which may require or benefit from such improvements. In this way, the SST is assigned only the cost of those improvements which it uniquely requires. Aircraft types considered in this examination are:

- current subsonics
- stretched subsonics (DC-8-63)
- high-capacity subsonics (Boeing 747)
- Concorde
- SST

II. OBJECTIVES

The objective of this aspect of the total study is to identify the major costs of improvements and modifications to enroute support services which may be required to satisfy the operational demands of advanced, high-capacity jet airliners--especially the SST-- which are expected to enter commercial service by 1975. Investigation of the airborne aspect was directed toward a determination of associated public costs and allocation of unique cost burdens among sponsoring aircraft types.

III. EFFORT PLAN

The plan derived to identify potential costs for improved enroute support services which may be required to ensure safe and efficient operation of the SST is as follows:

1. Perform a comprehensive literature survey of information regarding the capabilities of existing systems in the three areas considered in this part of the analysis (airways, navigation and communications; meteorology; and radiation).

2. Survey all information regarding requirements for efficient and safe operation of stretched subsonics, high-capacity subsonics, Concorde, and SST.

3. Conduct personal interviews with appropriate personnel of cognizant government agencies including FAA, Departments of Defense and Commerce, and NASA.

4. Assimilate discrete inputs into total requirements for enroute support of the SST.

5. Place the requirements into one of the enroute support systems: airways, navigation and communications; meteorology; or radiation.

6. Provide cost estimates of the discrete requirements for each of the three enroute support systems.

7. Allocate these costs among sponsor aircraft.

IV. COST ALLOCATION TECHNIQUE

Because the SST will not join airline fleets until 1974-1975, it was necessary also to investigate and identify the impacts to airports and airways of those aircraft types which will precede an SST into commercial airline service. The total study effort was directed toward allocating--for each ground facility and enroute support service improvement which may be required by an SST and/or by other advanced high-capacity aircraft--the U.S. supersonic transport's appropriate share of the estimated public costs, attributing proportionate shares among the:

- current subsonic family
- stretched subsonics (DC-8-63)
- high-capacity subsonics (B-747)
- Concorde

A. The Airborne Aspect-Cost Allocation

The cost allocation methodology employed is applicable only to commercial aviation, i.e., to the common carriers, and deliberately excepts general aviation and national defense activities. Where national defense programs were identified which also benefit any of the above-mentioned aircraft, costs associated therewith were separately accounted for. An example of such a defense program is research into radiation effects upon aircrews of very high-altitude aircraft, such as the U-2, RB-57F, and XB-70. Costs identified in this study are those for research and development and for procurement and construction.

The technique for cost allocation is straightforward. Modifications which would be required because of increased air passenger traffic, normal programmed maintenance, and obsolescence and exhaustion of existing facilities and systems (if only those aircraft now in commercial service were to be considered) were made the cost baseline. Incremental improvements and modifications beyond this cost datum were identified with one of the four advanced aircraft types expected to join airline fleets by 1975.

The advanced, high-capacity airliners might each have required some modifications to enroute services. Intensive investigation disclosed however, that only for the supersonic commercial jets is this the case. The Federal Government, having the responsibility for safety of flight, provides whatever enroute support services are necessary. The SST and the Concorde will require enroute support services to 70,000 feet, such as radiation measurement, prediction, and observation; weather reporting and forecasting; and continuous communication capability between the aircraft and ground control.

B. The Airborne Aspect-Cost Recovery

Cost allocation is a management tool for guiding the decision maker in choosing among available alternatives:

- whether to construct "system" A, B, C, or D
- whether a mix or combination of "systems" would be preferable
- whether to construct any of the proposed "systems."

Intended and developed solely as one of many predecision guide for weighing opportunities for action, cost allocation attempts to predict and approximate the investment (the resources commitment) which each of the feasible options would require. Cost allocation is not a plan for recovering the resources commitment once the (selected) system becomes fully operational. That process is called "cost recovery." Cost allocation occurs before the fact--prior to the decision. It is a management tool. Cost recovery occurs after the fact--after a new system becomes operational. It is the product of a management decision. In the real world, cost recovery defines precisely and according to sound accounting principles the contract between provider and user in economic terms.

Within the aviation community, the rationale and procedures which are actually observed for determining "how to pay" for an improvement are quite different from those followed in predecision cost allocation.

In actual practice, the recovery of system improvement costs would probably take the form of government-imposed user-charges, such as passenger fares and fuel taxes. Where such a scheme appears practicable, the recovery assessment might be charged only to benefitting aircraft.

V. SYSTEMS STUDIES WITHIN ENROUTE SUPPORT AREAS

In the following three sections of this volume, each of the three enroute support areas is examined separately in order to identify the systems improvements needed to fulfill SST requirements. The respective areas are discussed as follows:

Section VI - Airways, Navigation, and Communications

Section VII - Meteorology

Section VIII - Radiation Monitoring

Each of the present systems is examined and compared with SST requirements to indicate deficient areas. The planned and conceptual systems proposed for the future are then discussed and compared with SST requirements. The modifications required to satisfy commercial aviation needs in the particular enroute support areas are identified and costs allocated to the aircraft types in the manner described in Section IV of this volume, Cost Allocation Technique.

VI. AIRWAYS, NAVIGATION, AND COMMUNICATIONS

A. Requirements of Commercial Aviation through 1975

The effect of air traffic congestion is becoming increasingly important to commercial air transportation. To the passenger, congestion manifests itself in the form of delays at takeoff and landing which cause late arrivals, missed connections, and unplanned stopovers. To the airline, congestion means increased fuel and crew costs, frequent changing of planned operations, and increased passenger service costs.

Continued growth of air travel, the planned introduction of stretched and high-capacity subsonic aircraft, and in the 1970's the advent of the SST will compound this problem. Predictions are that by 1975 an instantaneous maximum of 230 flights per hour can be expected during peak season in the North Atlantic Region[1] (see Exhibit 1). Included in this traffic will be a mix of current generation subsonic jets and supersonic airliners. To illustrate the magnitude of this predicted increase, note that approximately 300 flights per day were scheduled during the peak summer period over the North Atlantic in 1965.[2]

Practical considerations prevent a completely new and different control system for every aircraft. The evolutionary process which has characterized the development of the existing combination of navigational and communication aids will continue. Increased use of automation will be necessary in order to handle the projected air traffic. The period between 1965 and 1975 will see the introduction of both advanced subsonic aircraft and supersonic equipment. Proposed, advanced subsonic aircraft, such as the Boeing 747, are designed to carry up to 500 passengers. Even larger airplanes have been predicted as practicable.

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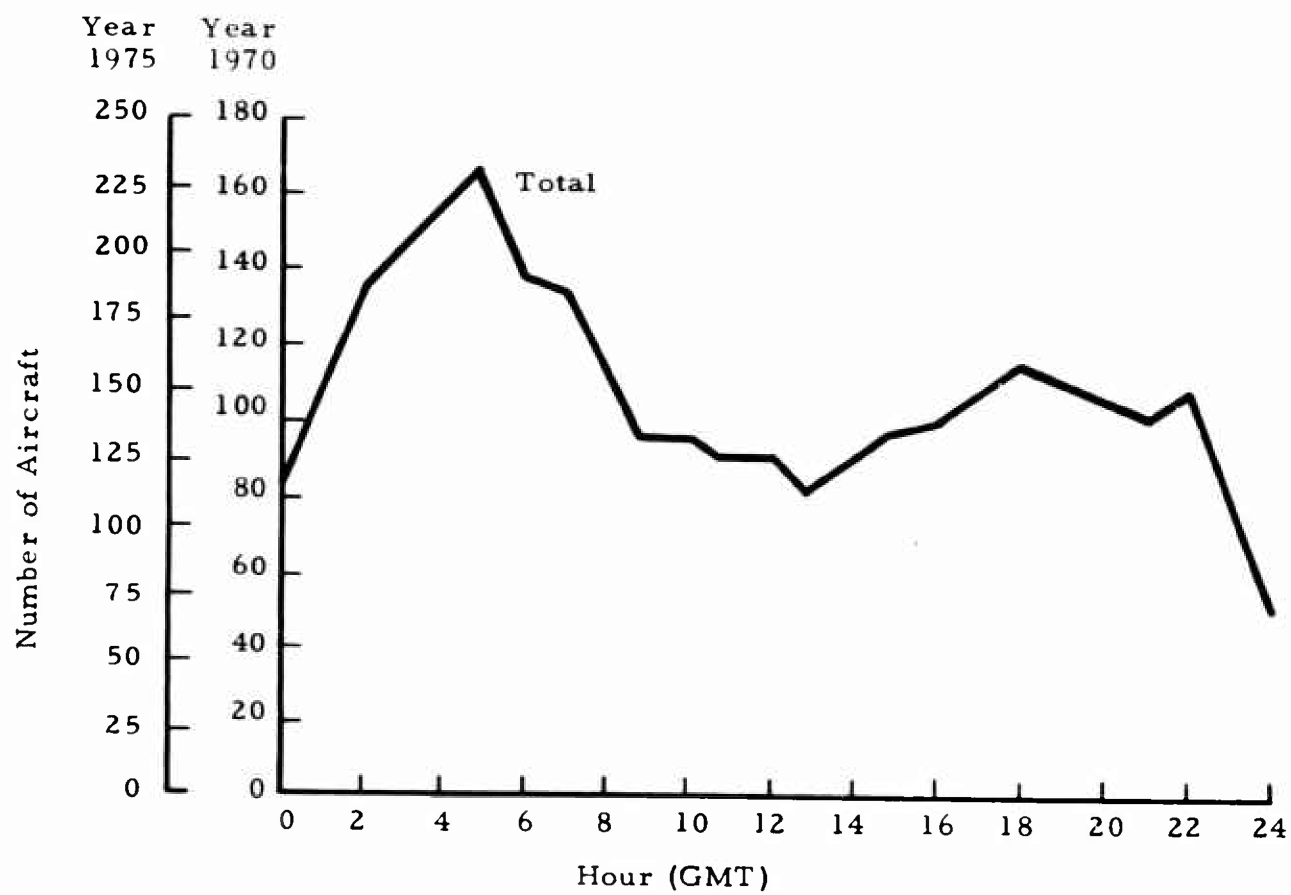
[1] System Sciences Corporation, Selected Navigation and Communication System Concepts for 1975, April 1966 (an evaluation for NASA)

[2] Official Airline Guide, International Edition, August 1965



Source: (a) System Sciences Corporation, <u>An Analysis and Technical Evaluation of Selected Navigation and Communication System Concepts for 1975</u>, April 1966

EXHIBIT 1 - ESTIMATED MAXIMUM INSTANTANEOUS AIRBORNE COUNTS IN THE NORTH ATLANTIC REGION (1970-1975)

The supersonic transport will multiply the present jet aircraft speed by a factor of three and increase cruising altitude to a level almost twice that of today's commercial vehicles.

One of the basic ground rules imposed upon the design of the SST has been that it must be compatible with the air traffic control environment in which it will operate. Simulated SST air traffic control problems indicate that the airplane cannot be given extended preferential treatment because of its disrupting effect on other traffic.

Expanded use of inertial navigation systems and data-link communication devices by commercial aircraft will relieve a suitably equipped aircraft from dependency on externally supplied data. An inertial navigation capability is essential on long overwater flights where radio navigation aids are inherently unreliable and inconstant. There will still be a requirement for position verification data from external ground sources, but this need can be filled by use of existing aids, such as LORAN and VORTAC, or by 1975 by navigation satellites.

Thus, the major requirement on airways, navigation, and communications systems through 1975 will be to serve effectively the increased numbers of commercial aircraft, since the aircraft types to be introduced through that period of time will be designed to operate within enroute support systems which require no new technological breakthroughs.

B. Present Systems

1. Domestic Environment

As a result of Project Beacon,[1] the National Airspace Utilization System (NAS) was developed and is now being systematically implemented to provide safe, efficient handling of air traffic through 1975. Modifications are continually being made to the overall design to incorporate improvements in technology and procedures.

[1] Federal Aviation Agency Report of the Task Force on Air Traffic Control, Project Beacon, October 1961

The domestic air traffic control system (ATC) is a dual-use system providing control and guidance for civil as well as military operations. Available military control facilities have been used to the maximum to eliminate costly duplication of men and equipment.

Spatial segregation is the basic concept on which the NAS approach is founded. Standards have been established which define airspace as either controlled or uncontrolled. Each of these two areas is further divided to monitor aircraft entering the area, in order to ascertain whether or not they are adequately equipped to maintain safe operation. The ceiling under positive control has been increased to 100,000 feet with 5,000 feet of vertical separation, a procedural change[1] that will assure the SST the same degree of surveillance as that given other traffic. No additional equipment will be required; in fact, high-altitude military operations are routinely tracked on existing equipment. VORTAC is the ground-based radio navaid used for the enroute, transition, approach, and departure phases of flight. Coverage is provided in all controlled airspace up to the cruising altitude of an SST. While the SST will depend primarily on a self-contained navigation system, VORTAC will be available for checking and updating inertially derived data.

Airports are grouped into five categories on the basis of the levels of activity and facilities available. Although the first three categories include most United States airports, for purposes of SST evaluation those in Categories 4 and 5 are a matter of concern.

Characteristics of these airports are:

> "Category 4 airports are equipped with terminal radar traffic control. Radar is used in the provision of both IFR and VFR air traffic control services. Civil and military airports of this type number approximately 100 each."

[1] Federal Aviation Agency, Advisory Circular Order 7100.1A, 15 June 1966

> "Category 5 airports are those located within a complex of airports (metroplex) where the concentration and mixture of high and low performance aircraft are such as to require the subdivision of airspace so that all aircraft operate under ATC control. The airspace surrounding one or more major airports in such complex terminal areas will be designated positive control. There are between 12 and 20 civil and military terminals of this type."[1]

Progress is being made in the field of all-weather landing systems. At present, there are four airlines qualified to operate at Category II landing minimums and five airports (Dulles, Pittsburgh, Oakland, Atlanta, and Louisville) are currently equipped and qualified to operate under Category II conditions.[2]

The hub of the enroute ATC system is the air route traffic control center (ARTCC). At present, there are 21 ARTC centers located in the continental United States. These facilities exercise control over air traffic transiting their geographic regions and coordinate the movement between regions. Each center receives enroute primary radar and secondary radar (transponder beacon) data within the center-controlled area from remote radar sites. This information is processed and portrayed as a composite picture of actual air activity, and potential collisions are identified and prevented.

The primary ATC subsystem is based upon a system of sectors, or volumes of airspace with defined boundaries within which a single controller (assisted by other personnel and equipment) has exclusive control over all aircraft receiving control services. Increased traffic density has brought about the introduction of computers to assist the controller in the routine phases of his job. Previously, when traffic increased, modifications were made to the size of the affected sectors

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[1] Federal Aviation Agency, Systems Research and Development Service, Design for the National Airspace Utilization System, Summary Edition, September 1962, p.21

[2] Air Transport World, March 1966, p.48

rather than changes to the tasks performed by the sector controller. In 1965, the FAA was operating 452 sectors and estimated that there would be an increase of 20 percent within 10 years unless steps were taken to automate the nonjudgment functions of a controller's workload.

The 1966 version of the air traffic control system is a system in transition. Various parts of the future fully-automated system are being introduced on an individual basis. A strong foundation exists on which to build a control system adequate to provide sufficient control over the traffic predicted for the 1970's.

2. North Atlantic

The North Atlantic region represents the most important market for the SST during the introductory period. This is the area in which the vehicle will probably be first introduced into commercial airline service, due to the close matching of aircraft performance characteristics and market characteristics. It has been estimated that one out of every three supersonic transports built will be assigned North Atlantic routes.[1]

Congestion is today a major problem over the North Atlantic region. This congestion occurs during the enroute portion of the flight rather than during the terminal phase, as is typical of many domestic U.S. flights. While there may be some terminal delay backup into the enroute segment, the major source of delay is due to separation standards. Separation criteria which are now in effect on the same or diverging routes over the North Atlantic are:

- Vertical separation--2,000 feet
- Lateral separation--120 nautical miles
- Longitudinal separation--15 minutes of arc

These separations are necessary because of the lack of positive radar control throughout the full transit of the ocean.

[1] Supersonic Aircraft in the North Atlantic, Commander Curtis J. Kelly, United States Coast Guard, New York, N.Y., 17 June 1964

On November 6, 1961, the Federal Aviation Agency appointed a team of experts to develop a systems approach to the navigation and communications problems associated with operations in the International Civil Aviation Organization's (ICAO) North Atlantic Region. This "Systems Planning Approach North Atlantic Team" (SPANAT) recognized as its major responsibility the design of a system to provide efficient service through the 1970's. The SPANAT Staff Study[1] associated the efficiency of the present system with the ability to compress separation standards. As a result, the Federal Aviation Agency attempted in January 1966 to reduce the lateral separation standard from the current 120 nautical miles to 90 nautical miles, a proposal resisted by organizations representing pilots who operate in the affected area. After FAA-sponsored hearings on this matter, the reduced separation proposal was withdrawn because of the economic hardship that would be imposed on the air carriers by the aircrews selecting circuitious routings as alternatives to the more efficient flight profiles under the new rules. It is reasonable to expect that by the time the SST is operating, reduced lateral separation of aircraft over the North Atlantic will have been adopted with the support of (presently) contesting parties as a result of the improved accuracy of navigational and airborne communications equipment.

A distinct and directional peaking of aircraft flow in the North Atlantic region occurs regularly. A disproportionate number of the eastbound flights arrive at 50°W (transitional area) during the early morning hours (0100-0500 Greenwich Mean Time, GMT), and there is a corresponding westbound imbalance during late afternoon (1500-2100 GMT). Exhibit 2 presents an hourly percentage distribution of daily flows by direction.

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[1] Federal Aviation Agency, (Staff Study, Systems Planning Approach North Atlantic Team), A System Design for the Provision of a Safer, More Economic, and More Efficient Air Traffic Service for the ICAO North Atlantic Region, August 1964

EXHIBIT 2 - AVERAGE PERCENTAGE DISTRIBUTION OF DAILY FLOWS BY HOUR (1964 PEAKING PATTERN)

Hour at 50° W (GMT)	Percent of Daily Flights	
	Eastbound	Westbound
0000-0100	2.7	1.3
0100-0200	12.1	0.9
0200-0300	21.9	0.6
0300-0400	17.3	0.3
0400-0500	15.1	0.2
0500-0600	8.3	0.3
0600-0700	4.7	0.3
0700-0800	2.1	0.3
0800-0900	1.0	0.7
0900-1000	0.6	0.4
1000-1100	0.6	0.2
1100-1200	0.2	0.2
1200-1300	0.2	0.3
1300-1400	0.2	2.7
1400-1500	0.2	6.0
1500-1600	1.4	9.6
1600-1700	7.7	14.1
1700-1800	1.6	18.2
1800-1900	0.4	12.7
1900-2000	0.2	12.2
2000-2100	0.3	8.8
2100-2200	0.2	5.5
2200-2300	0.2	2.9
2300-2400	0.8	1.3
	100.0	100.0

Source: (a) Institute for Defense Analyses, The North Atlantic Air-Traffic Control System, Economic Analysis of Proposed Changes, September 1965, p. 25

The immediate problem within the North Atlantic airspace is not the introduction of the SST, but rather the effects of the tremendous increases in traffic over the route. At any given time, there are only a limited number of available aircraft routings across the principal area. These track choices are dependent on the airplane's performance characteristics and winds aloft, but temperature will be the most critical factor. The SST is less vulnerable to wind than is the subsonic jet because of its high cruise speed. Enroute temperature is quite critical for an SST; therefore, optimum tracks for supersonic aircraft should be dissimilar to those which are advantageous to subsonic vehicles.

The basic communications system available over the North Atlantic is a combination of VHF and HF coverage. VHF communication is used at the near-terminal sections of the flight; HF coverage is used during the overwater enroute portion of the flight profile. These communication services, as well as traffic control, are provided by the Gander and Shanwick Oceanic Control Centers. Exhibit 3 illustrates a typical SST flight profile for a flight between New York and London and depicts the services available to aircraft transiting the region.

Present airborne navigational devices aboard intercontinental airliners range from inertial devices to celestial optics. The latest avionics suits include inertial systems on the newest aircraft. Several airlines are considering the merits of retrofitting their entire fleets with inertial systems in order to realize the potential savings which result from the shorter flight time and reduced fuel consumption that should be possible because of more precise navigation. Fuel economy will be most important to the SST because of the exceptionally high fuel flows of their engines. Any improvement in fuel consumption on a range-payload sensitive aircraft could be converted into the ability to carry additional revenue passengers.

Inertial navigation basically eliminates the crew's dependence on electronic signals from the ground. Such a self-contained airborne system eliminates the requirement for any new facilities and modifications to existing installations.

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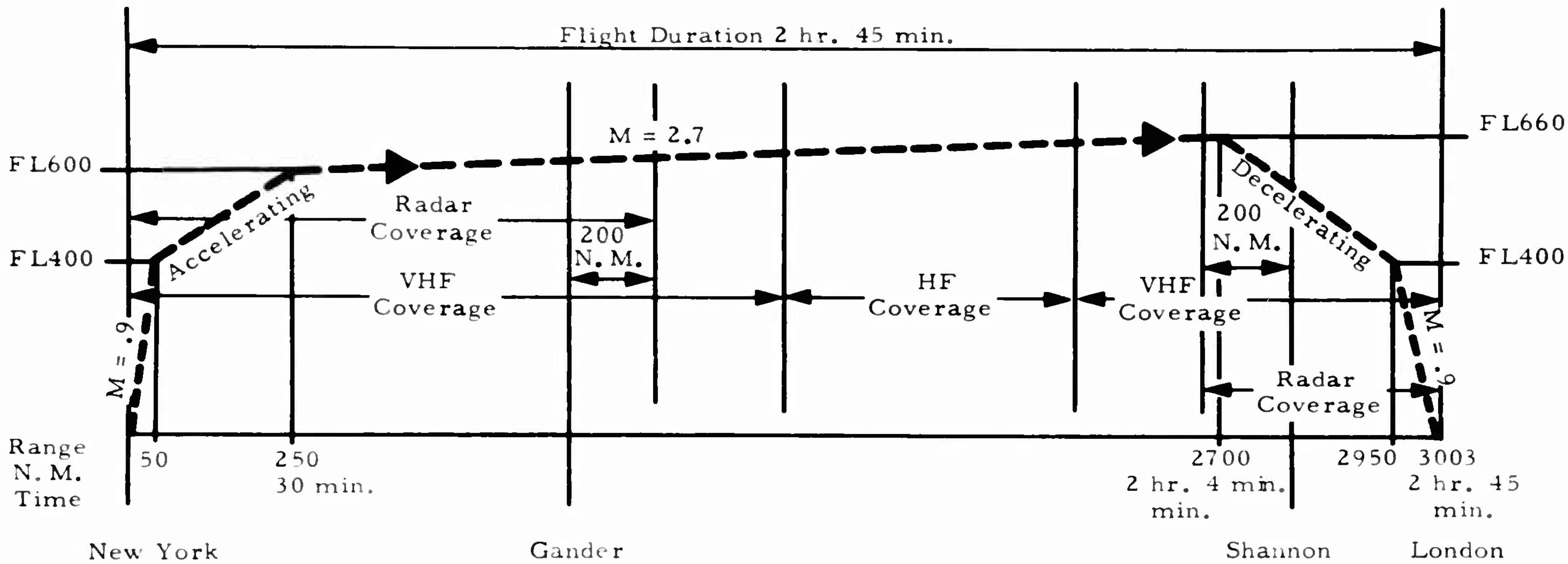

Source: (a) Supersonic Aircraft in the North Atlantic, Cdr. Curtis J. Kelly, U.S. Coast Guard, New York, New York, 17 June 1964

EXHIBIT 3 - TYPICAL SST PROFILE

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C. Evaluation of Present Systems: NASA-FAA Simulation Program

A joint NASA-FAA simulation program[1] has been in effect since 1963 for the purpose of evaluating the problems associated with introduction of an SST into the air traffic control environment. The program is conducted at NASA's Langley Research Center at Langley, Virginia and the FAA's National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey. SST flying characteristics are generated by a Langley-based simulator and the air traffic control situation is simulated by use of equipment located at NAFEC. Through parametric simulation, it is possible to vary both the vehicle and environmental envelopes and thereby investigate the effect upon the overall system.

Early studies were limited to operating problems in terminal areas and did not consider the enroute segment. Later tests extended the simulation to include an exchange between air route traffic control centers during transcontinental flight. Results indicate that the enroute segment does not appear to be the primary source of difficulty for the SST because it will be cruising above the congested subsonic airways.

The test program was designed to process, on a real-time basis, a simulated mixed-traffic sample of arrivals and departures to and from John F. Kennedy International Airport with the use of both present-day and advanced ATC equipment. The controlled area was a 400-nautical mile square and the sample was exercised during current peak activity conditions (148 operations per hour including 6 SST operations). A typical distribution of this sample was the following:[2]

Propeller Aircraft	Subsonic Jet	Supersonic Jet
24 arrivals	39 arrivals	3 arrivals
22 departures	51 departures	3 departures
1 overflight	5 overflights	

[1] Joseph P. O'Brien and Richard H. Sawyer, "Simulating SST Operations - The Background," Astronautics and Aeronautics, May 1966

[2] Department of Commerce SST Economic Analysis G Group, Preliminary Report, 1965

During the early part of the program, it became apparent that ascent and descent profiles (see Exhibits 4 and 5) would be difficult to maintain because of the sonic boom overpressure limit[1] and the sensitivity of the vehicle due to a high thrust-to-weight ratio during subsonic climb. Violation of the sonic boom limits occurred on many of the climbouts performed by active airline flight crews. These crews commented that the workload associated with a manual flight-path control system in conjunction with conventional instrumentation was excessive for normal airline operation and that some form of automatic throttle control should be designed for future evaluation (Exhibits 6 and 7). Use of a Flight Director for flight path control guidance during the climb and descent modes is currently being evaluated and preliminary results indicate that this aid will improve control of the vehicle.

Tests have been conducted[2] to determine that effectiveness of a priority SST air traffic control system. Basic changes for the priority system were made in radar and altitude separations and priority of sequencing for arrival and departure. While it appears that some priority handling may be given the SST, the approach used in the NASA-FAA simulation program imposes severe delays on the majority of the traffic. Increased separation standards (Exhibit 8), both in the air and on the runways, exert a greater effect on the ATC system than do preferential SST procedures. When the simulation was operated at the increased separation standards, severe system penalties were incurred in the form of reduced operation rates, increased controller workload, and overall system delay. Some of the results of this study were:

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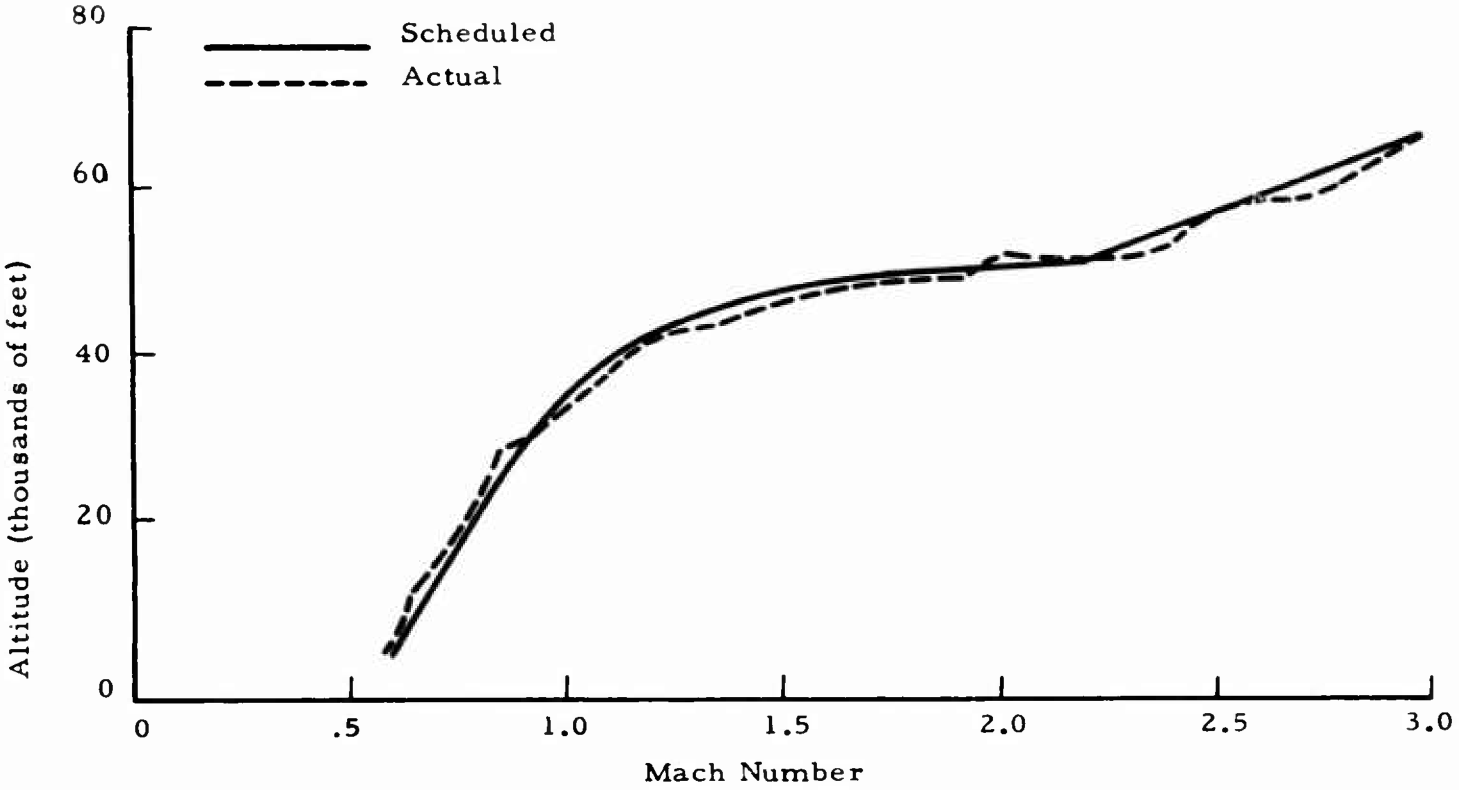
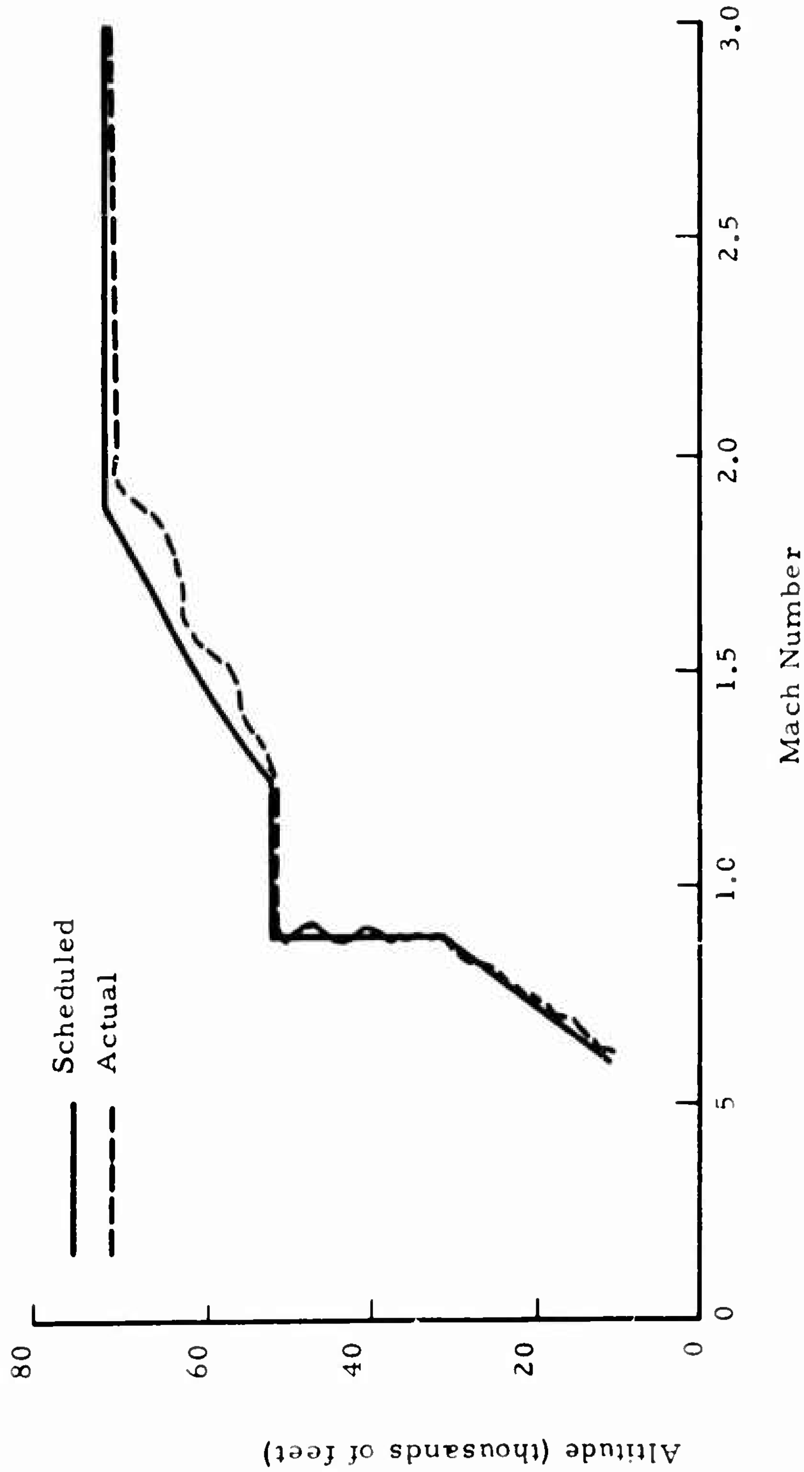
[1] Simulation Study of SST Terminal Area Navigation in the ATC System, Richard H. Sawyer, Michael C. Fischer, and Joseph P. O'Brien, presented at 16th International Air Transport Association Technical Conference, Miami Beach, Fla., April 22-30, 1965

[2] Federal Aviation Agency, Experimental ATC System Branch, Air Traffic Control and the Supersonic Transport, Donald S. Schlots, 16 August 1965



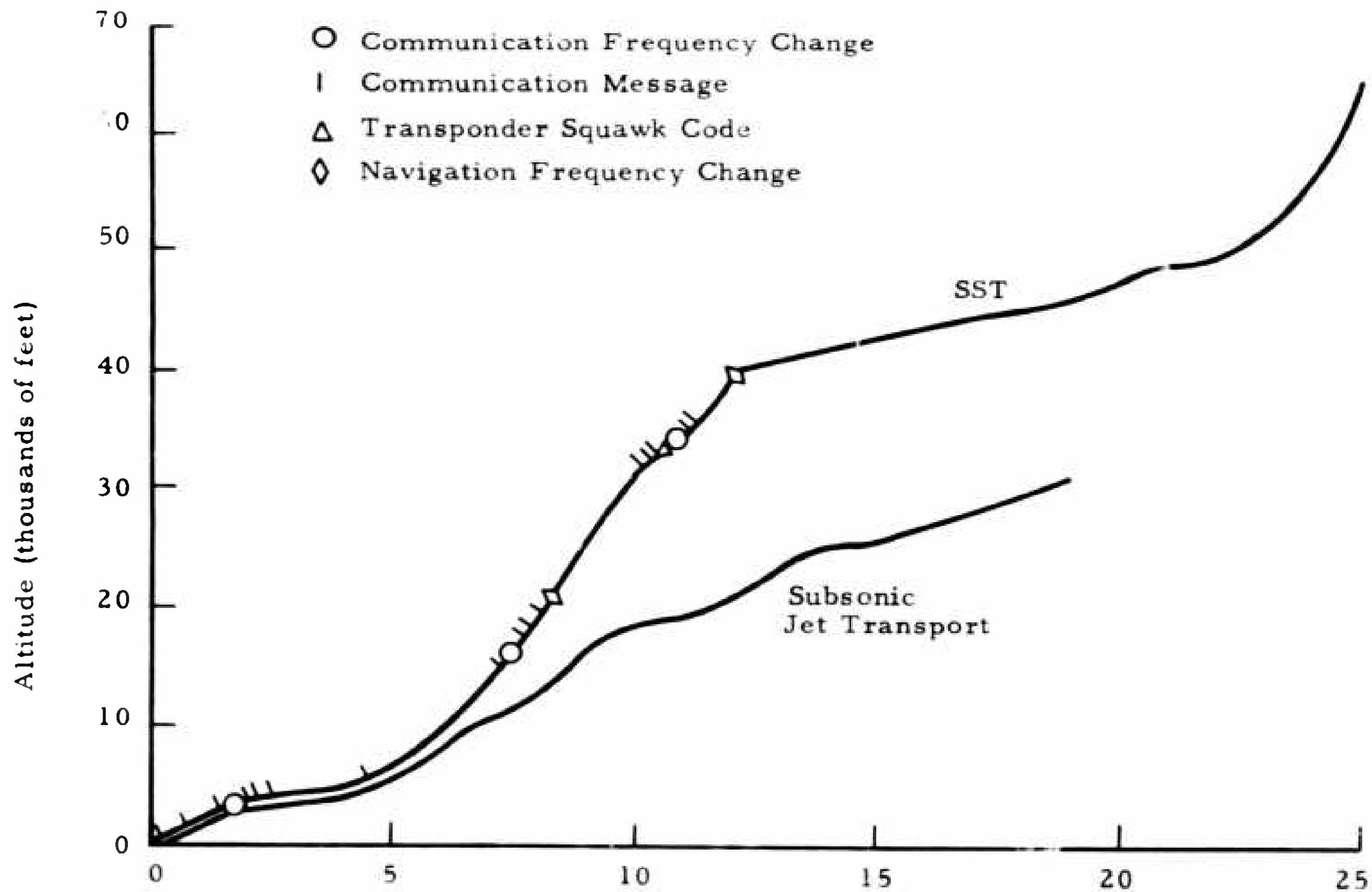
Source: (a) NASA Langley Research Center, <u>Simulation Studies of the Supersonic Transport in the Air Traffic Control System</u>

EXHIBIT 4 - SCHEDULED AND ACTUAL ASCENT PROFILES



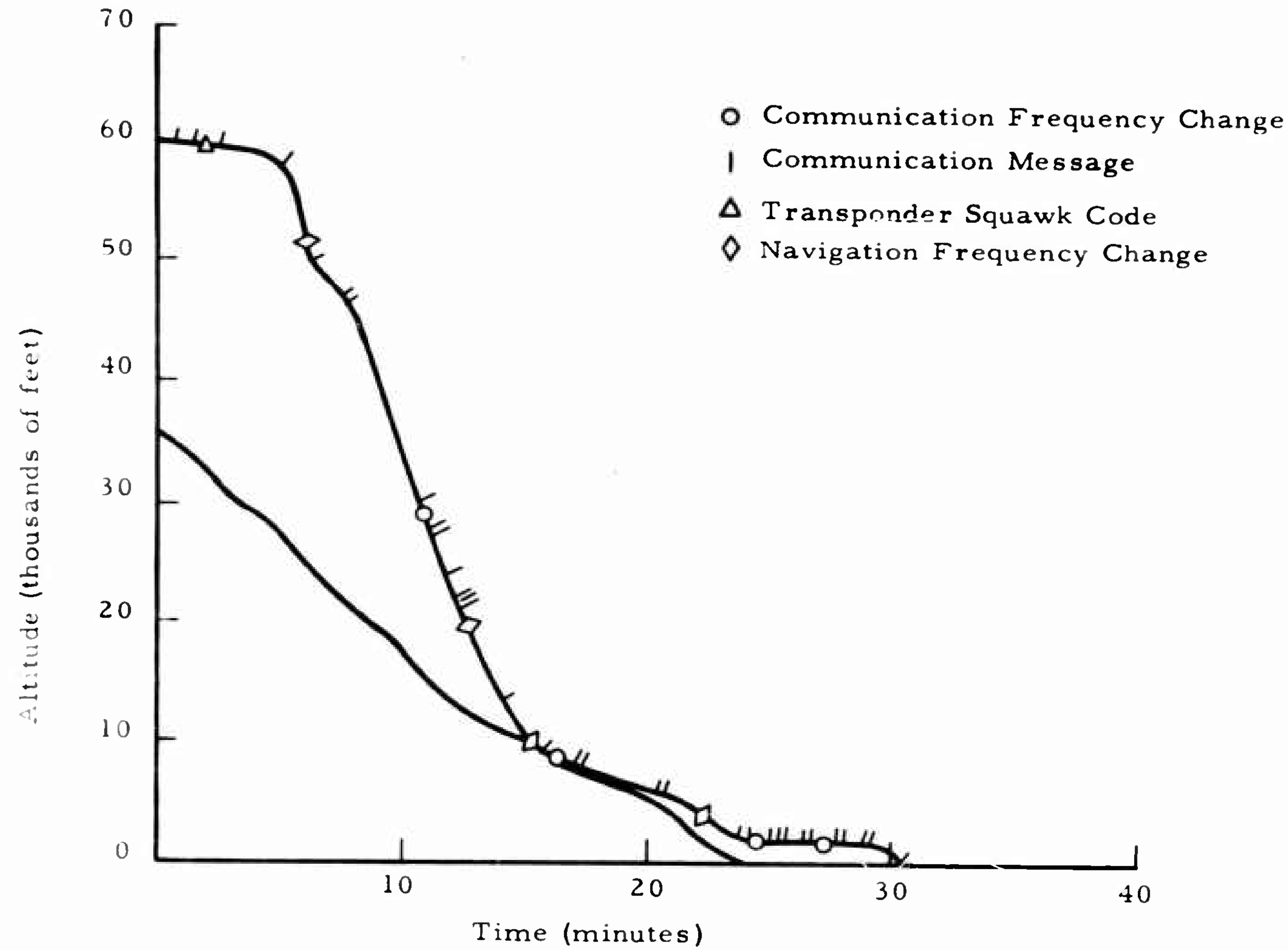
Source: (a) NASA Langley Research Center, Simulation Studies of the Supersonic Transport in the Air Traffic Control System

EXHIBIT 5 - SCHEDULED AND ACTUAL DESCENT PROFILES



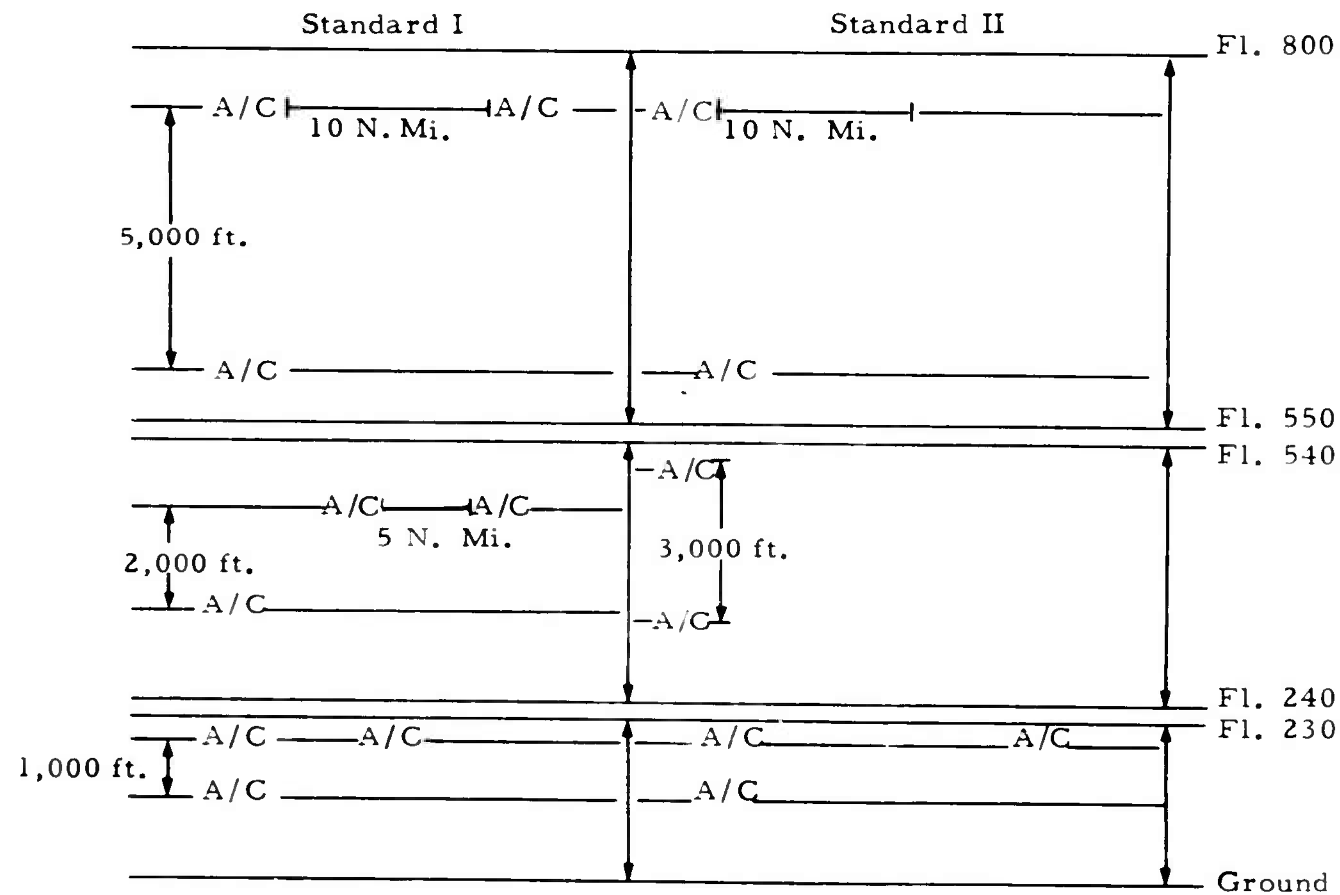
Source: (a) NASA Langley Research Center, Simulation Studies of the Supersonic Transport in the Air Traffic Control System

EXHIBIT 6 - CREW WORKLOAD DURING ASCENT



Source: (a) NASA Langley Research Center, Simulation Studies of the Supersonic Transport in the Air Traffic Control System

EXHIBIT 7 - CREW WORKLOAD DURING DESCENT



Source: (a) Federal Aviation Agency, NAFEC, Air Traffic Control and the Supersonic Transport, Donald S. Schlots, 16 August 1965

EXHIBIT 8 - EXPERIMENTAL SEPARATION STANDARDS

- Subsonic traffic incurred long radar vectors and excessive air and ground delays.
- Airport acceptance rates were reduced (in some cases to 48-50 operations per hour) from the theoretical maximum of 60 operations per hour in the priority system.

Results of the initial NASA-FAA Simulation Program indicated a need for the following:

- An improved pitch-trim control and flight instrumentation for vertical flight path control.
- Automatic throttle control for climb and begin-cruise conditions.
- Transonic acceleration track approximately 100 miles long with neither heading nor altitude restrictions.
- Limited supersonic heading changes due to intensification of sonic boom in a turn and the possibility of airways overshoot.
- Provision for separate SST approach and departure routes.
- Visual display of aircraft position relative to planned position.

Evaluation of information generated during the initial phases of this program has resulted in modification of the simulation. These changes are being evaluated by NASA and FAA against both the basic ATC system and the systems envisioned for 1970 and 1975.[1] The traffic sample has been changed to make it comparable to the volume expected in 1970. A 4-hour traffic sample has been compressed into 1-1/2 hours to represent this increased traffic and is being exercised in the simulator routine. No attempt is being made to land this volume of traffic at Kennedy International Airport because today's facility does not have the capacity to handle such a volume. The simulation is presently concerned with the air activity in the terminal environment.

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[1] Simulation Studies of the Supersonic Transport in the Air Traffic Control System, by Richard H. Sawyer, NASA-(Langley) and Joseph P. O'Brien, FAA, (Paper presented at the 1965 SAE National Aeronautic Meeting and Production Forum)

D. Future Systems

1. Planned Systems

The planned systems discussed in this section are part of the evolutionary change from the present, largely manual air traffic control system to one with increased safety and greater systems capacity. A step-by-step program to increase present-day automation is being developed. At least partial implementation can be expected by 1970 in both the terminal and enroute environments. The program is commonly referred to as the National Airspace System (NAS).[1]

Under development for terminal control is the Advanced Radar Traffic Control System (ARTS),[2] which includes track-while-scan alphameric identity for selected targets and automatic target-data box association. The first field trial model is undergoing evaluation at the Atlanta Air Route Traffic Control Center. Portions of the system are programmed for some 23 terminal areas, and a field trial in the en-route environment is planned at Indianapolis. In addition to the test model at Atlanta, nine terminal areas will receive partial implementation of ARTS. Essentially, this portion of the program will provide radar and beacon alphamerics for terminal area use by displaying identity and altitude information from transponder-equipped aircraft on bright displays. These systems will not be capable of tracking primary radar data. Initial installation is planned for Kennedy, O'Hare, and Los Angeles Airports.

Although ARTS is a major step forward, its limitation to inputs from a single radar system does not permit sufficient growth for use at large, multi-airport terminal areas. For these areas (e.g., New York, Los Angeles, or Chicago), the NAS metroplex concept[3] is being developed. This concept will be a follow-on to the radar and beacon alphamerics discussed above.

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[1]Federal Aviation Agency, Systems Research and Development Service, Design for the National Airspace Utilization System, Summary Edition, September, 1962

[2]Federal Aviation Agency, 5-Year Program (as revised February 24, 1964)

[3]Federal Aviation Agency, National Airspace System, System Description, April 1965

The NAS system for the enroute environment will be implemented in two phases. NAS Stage A will include the automation of many enroute functions. NAS Stage B will complete the air traffic control subsystem as envisioned by the FAA Systems Design Team. The NAS-ATC Subsystem (Stages A and B) was designed to satisfy operational requirements expected to exist through 1975 and conceivably after that time.

Planned improvements to the air traffic control system for purposes of evaluation are assessed by enroute environment and terminal environment. Enroute environment is examined by domestic and international environments; terminal environment by transition (approach and departure), instrument approach, all-weather landing systems, and airport ground control

a. Enroute Control

(1) Navigation

(a) Short-Range

Presently available equipment in the short-range class of ground-based navigation systems includes VOR (Very High Frequency Omniranges) and TACAN (Tactical Air Navigation). These system equipments in combination are referred to as VORTAC, which is the basic system used by airlines in the United States. Commercial aircraft rely on VOR for azimuth guidance, and on the DME (Distance Measuring Equipment) portion of the military TACAN system for line-of-sight distance determination to signal source.

FY 1965 implementation of the VOR and VORTAC systems numbered 873 installations in the continental United States with expansion programmed to 1,100. At completion of the program, an effective short-range navigational capability will exist over those parts of the United States which are regularly overflown by other than private, basic aircraft. VOR/VORTAC equipment is also the international standard and is being installed in many countries of the world. Complete airway installations are programmed for the United Kingdom, France, Germany, Switzerland, Italy, and the Middle East.

The standard VORTAC system could be used as a navigational aid for the SST; however, its line-of-sight characteristics would limit its usefulness because the air crew would be continually busy changing radio channels. This hybrid system provides navigational data free from static and interference, but it is limited to short-range transmissions. The range of the system is dependent on the altitude of the user aircraft. Approximate maximum range is 200 nautical miles with an accuracy of 0.25 nautical miles. Lack of automatic position-fixing is another limitation of this technique. The VORTAC system will most likely continue as a basic navigational aid at lower levels and will be available for position referencing of inertial navigation systems.

(b) Pictorial Display and Off-Course Computer

One early result of the NASA-FAA Supersonic Transport simulation program was a requirement for some form of visual position display. The primary purpose of pictorial display during flight is to present the output of the navigation system with reference to the planned aircraft track. In the terminal area, the equipment would provide a continuous real-time portrayal of position and track with relation to established arrival and departure corridors, VOR/DME beacons, turning points, etc. An off-course computer combined with a pictorial display has been installed in the Langley flight simulator for evaluation.

Currently envisaged SST equipment would be an integral part of the flight control and navigation system. Displays would be generated either by the self-contained inertial navigator monitored against LORAN, by VOR/DME, or directly from a suitable external support system. No additional ground equipment would be necessary. Pictorial cockpit displays (PD's) and course-line computers will not be limited to supersonic transports but will probably enjoy wide acceptance in all aviation areas.

(c) Long-Range (Hyperbolic)

Equipment in this class includes: LORAN-A, LORAN-C, DECCA, OMEGA, CONSOL, and others. These systems are in varying stages of acceptance and implementation. LORAN-A has

been available since 1942 and is the most widely used of these hyperbolic approaches to navigation. According to the U.S. Coast Guard, as of September 1965 there were 81 LORAN-A stations operational throughout the world providing coverage over 40 percent of the earth's surface. As is true of most of these systems, meteorological effects do not appreciably degrade the quality of transmissions; they are considered to be all-weather systems. LORAN-C coverage is available in the North Atlantic and Mediterranean, off the Hawaiian Islands, in the Pacific Polar Region, and in the Far East around Japan. The nominal ground wave range of LORAN-C is 1,200 nautical miles, which is twice the capability of LORAN-A. No international standard has been established in the area of long-range navigation.

(d) Long-Range (Self-Contained)

The systems included in this area are: Doppler, Inertial, and Inertial Combinations. Use of a self-contained navigation system will provide the capability for worldwide all-weather operation exclusive of any conventional radio navigation aids. With this ability, an SST would be independent of ground navigation facilities and thus would not require complementary external navigation services. The primary navigation system for an SST will be inertially based and capable of continuously providing navigational information with a high degree of accuracy. Due to the speed of the SST, an inertial system will be inherently more accurate than available alternatives because accuracy in this system is a function of time rather than distance. It may be desirable to combine the basic inertial system with another self-contained approach to provide a means for rapid update of the inertially derived data, in order to maintain accuracy within tolerances compatible with projected lateral separation standards.

The improved accuracy of the inertial system (especially in the area of lateral separation) will be reflected in added safety and economy of operation. A series of tests was sponsored by FAA and conducted by Pan American World Airways which utilized DC-8 equipment on

regularly scheduled long-range flights.[1] The inertial navigator used in these tests was basically a short-range tactical military system converted for civil operation. The primary purposes of the tests were to demonstrate feasibility and to establish accuracy characteristics. The mean error for the 79 successful data flights was 2.56 nautical miles per hour,[2] and the last 19 successful flights demonstrated a mean error rate of 1.85 nautical miles per hour. With this degree of navigational accuracy, it should be possible to reduce the present North Atlantic lateral separation of 120 miles to a figure closer to that of domestic standards. Separation standards are keyed to the least accurate vehicle in the system. The FAA has proposed the following lateral separation standards[3] in the most critical areas:

Year	Lateral Separation
1966	120 nautical miles
1967	90 nautical miles
1975	60 nautical miles
1985	30 nautical miles
2000	15 nautical miles

These dates and the corresponding lateral separations shown are a general guide for planning purposes only.

[1] Sidney Hirshon, "Inertial System Capabilities Applied to SST Operation," Journal of the Institute of Navigation, Vol. II, No. 3, Autumn 1964

[2] One nautical mile is equal to 1 second of arc or 6,080 feet as against a statute mile of 5,280 feet.

[3] Federal Aviation Agency Planning Letter to National Aeronautics and Space Administration, dated 5 July 1966

(2) Communications

(a) Voice

Voice communications will continue during the next 15 years as the basic backup communication system in all aircraft. There is a continuing need to handle nonroutine messages of an advisory or emergency nature. Aircraft, especially general aviation aircraft, will certainly continue to rely on voice as their prime communication method. A refinement of voice communications will be the incorporation of SELCAL (Selective Calling) equipment. This will provide for automatic callup by which a specified flight can be alerted that a voice communication is being addressed to it. SELCAL equipment provides for the transmission from aircraft of an acknowledge signal upon interrogation by a properly coded SELCAL signal. This provides a means for reducing the voice communication associated with routine in-flight reporting; it has been considered as only an interim stage between the area of voice communication alone and the area of a complete automatic communication system. However, the SELCAL capability can be used for other purposes, such as ground-based position determination. This will be discussed later.

(b) Data Link

An experimental automatic communication system has been evaluated by the Federal Aviation Agency. This system (AGACS: Automatic Ground-Air-Ground Communication System) is being used to evaluate the modes and speeds of transmission necessary to ensure reliable communication under all atmospheric conditions. Studies have been carried out to determine the types of messages and operating procedures to be used with an automatic communication system. A final data link system is foreseen to be developed and standardized prior to the introduction of the supersonic transport. Such a system would be used primarily for the delivery of routine messages to the aircraft and the transmission from the aircraft of identity, altitude, and position. Requests for changes in clearances, emergencies, and other nonroutine messages will probably continue to be communicated by voice.

The interrogation cycle of the automatic system will be completely ground-controlled. It will be integrated into a ground-based processing and display system. To minimize the channel switching requirements for the SST, non-voice communications will probably be transmitted in the 750-1,000 bits-per-second range. The final form will depend on the evaluation results of the present experimental systems. It is expected that by 1970, regular users of the air traffic control system will be required to carry some form of automatic communication equipment as a basic part of the avionics complement.

The SST will use as its basic communication system some form of data link. During overflight of the continental United States, aircraft will rely on VHF and possibly UHF ranges. For transoceanic operations, either improved HF or troposcatter VHF communications will be employed. It is expected that direct pilot-to-ground communications will be continuously available over the routes to be flown by the supersonic transport.

Antenna design and placement will be a larger problem on an SST than on subsonic aircraft due to the thermal extremes experienced at Mach 2.7 speeds. This will be especially true of power and sensitivity requirements when a satellite-based communication system becomes operational, but tests indicate that flush-mounted antennae should be compatible with normal SST requirements.

b. Terminal Control

Terminal control includes airport traffic control towers and associated radar and tower equipment principally:

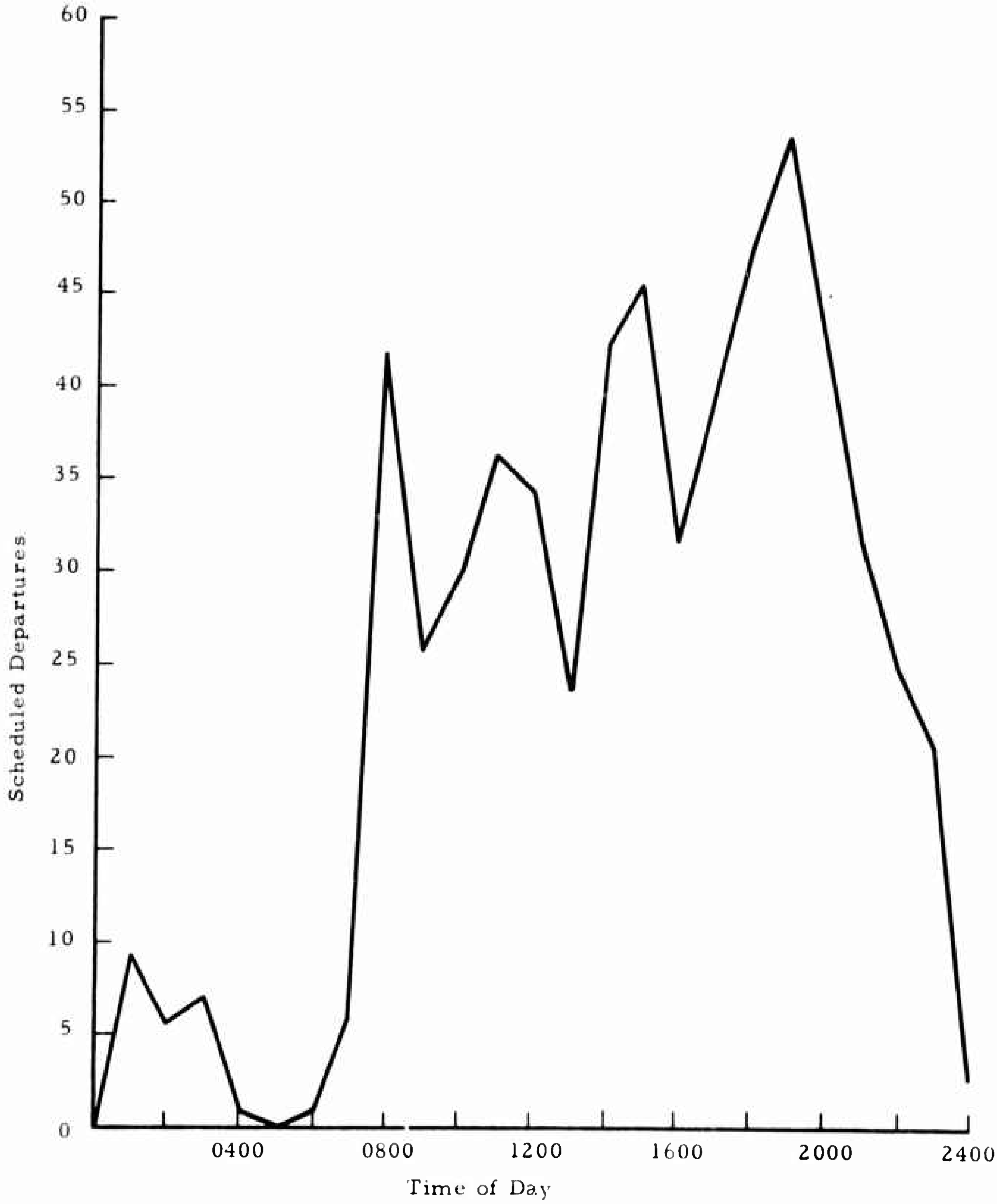
- Air Traffic Control Towers (ATCT)
- Airport Surveillance Radar (ASR)
- Radar Beacon (ATCRBS)
- Precision Approach Radar (PAR)
- Airport Surface Detection Equipment (ASDE)

As far as the terminal area is concerned, there will be no distinction between subsonic aircraft and the SST. The airport surveillance radar will be able to provide the necessary information to maintain the

established ATC separation standards. By increased use of terminal radar beacons, it will be possible to positively detect and identify properly equipped aircraft within a range of 200 nautical miles at altitudes from line-of-sight to the altitude at which an SST would normally cruise.

The objective of the terminal control system is to provide efficient service to arriving and departing aircraft while at the same time ensuring safe operations. While the SST has been designed to be compatible with subsonic traffic, it may require greater separation in the approach and departure modes due to vortices created by its size. Radar procedures presently require a 3-mile separation in the approach area beyond the outer marker. Runway intervals between aircraft are approximately 1 minute. If the SST should require greater separation between aircraft the service rate (capacity operations per hour) of the runways could be heavily penalized. If a 1-minute separation standard for arrivals and departures is assumed, there exists a theoretical maximum of 60 movements per hour per runway. Exhibit 9 shows the hourly distribution of scheduled departures during a typical day at Chicago O'Hare Airport. Distinct peaks exist in the distribution of departures, and future traffic growth will probably broaden the present peaks with only slight shifts of preference. As these peaks approach the maximum capacity of the facility, greater holding delays will be incurred and any vehicle which reduces the capacity will be subject to the cost of delays.

Exhibit 10 indicates the level of activity at the potential SST airports and measures the effect of increased movements on the facilities planned to be in use. Due to the greater seating capacity of current jet aircraft over that of piston airliners, there has not been a commensurate increase in the number of movements in relation to the number of passengers originated. During the period FY 1960 to FY 1965, the average number of passengers boarded per departure at the potential SST airports increased from 24.3 passengers to 38.2 passengers, an increase of 57.3 percent.



Source: (a) Official Airline Guide, September 1965

EXHIBIT 9 - HOURLY DISTRIBUTION OF SCHEDULED DEPARTURES--O'HARE AIRPORT, SEPTEMBER 1965

EXHIBIT 10- SCHEDULED DOMESTIC DEPARTURES AND ORIGINATING PASSENGERS FOR SELECTED AIRPORTS, FY 1960 AND FY 1965

Airport	FY 1960			FY 1965		
	Departures	Pass. Orig.	Avg. Pass. Dep.	Departures	Pass. Orig.	Avg. Pass. Dep.
Anchorage	4,719	79,913	16.93	7,497	197,767	26.38
Atlanta	75,079	1,114,236	14.84	91,904	3,347,384	36.42
Baltimore	17,901	320,628	17.91	27,766	757,680	27.29
Boston	51,129	1,397,744	27.38	65,950	2,493,859	37.81
Chicago (ORD)	38,060	1,382,715	36.33	191,890	8,418,880	43.87
Cleveland	52,532	1,020,284	19.42	54,271	1,534,044	28.27
Dallas	64,248	1,293,546	20.13	69,205	2,540,274	36.71
Denver	33,866	849,732	25.10	43,607	1,505,189	34.52
Detroit (DTW)	25,184	660,341	26.22	31,484	1,255,648	39.88
Fort Worth	26,339	162,006	6.15	8,326	30,888	3.71
Honolulu	18,360	380,064	20.70	28,145	1,115,438	39.63
Houston	29,640	619,807	20.91	37,507	1,186,918	31.65
Kansas City	36,753	715,061	19.46	37,854	1,205,845	31.86
[illegible]ngeles	71,705	2,745,212	38.28	104,326	4,976,364	47.70
[illegible]	46,927	1,581,306	33.70	53,319	2,437,051	45.71
[illegible]eapolis-St. Paul	37,031	785,712	21.22	35,860	1,320,102	36.81
New Orleans	29,437	636,248	21.58	34,405	1,066,670	31.00
New York (JFK)	58,074	2,242,650	38.62	116,735	6,053,194	51.85
Oakland	14,144	126,316	8.93	8,125	194,266	23.91

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EXHIBIT 10- (Continued)

Airport	FY 1960			FY 1965		
	Departures	Pass. Orig.	Avg. Pass. Dep.	Departures	Pass. Orig.	Avg. Pass. Dep.
Philadelphia	44,988	927,430	20.62	61,430	1,625,817	26.47
Phoenix	20,143	402,767	20.00	23,578	734,548	31.15
Pittsburgh	52,851	999,333	18.91	53,319	1,652,706	29.88
Portland	27,705	420,100	15.16	25,749	634,242	24.63
San Francisco	56,044	1,825,454	32.57	70,876	3,188,131	44.98
San Juan	17,255	636,366	36.88	25,983	1,264,557	48.67
Seattle	19,277	633,630	32.87	25,419	1,041,297	40.97
St. Louis	44,930	907,613	20.20	45,970	1,454,495	31.64
Tampa	26,582	427,410	16.08	29,270	762,431	26.05
Washington, D.C. (DUL)	-	-	-	11,926	384,985	32.28
Total	1,040,953	25,293,624	24.29	1,423,696	54,380,670	38.20

Source: (a) Civil Aeronautics Board/Federal Aviation Agency, Airport Activity Statistics of Certificated Route Air Carriers - FY 1960 and FY 1965.

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(1) Approach and Landing

All-weather operation of commercial transport aviation has been a goal for many years. Implementation of all-weather landings will occur in steps. The current phase is Category II. Category II capability will permit operation under conditions where the runway visual range (RVR) measures 1,200 feet or more. Aircraft will be guided during descent to 100 feet, at which height the pilot must see the runway or pull up and go around.

Category III has been divided into three distinct subcategories; the following requirements are preliminary in nature and are for planning purposes only:

- Category IIIA: RVE less than 1,200 feet and down to 700 feet; no decision height established; outside visual reference of the runway required; automatic touchdown and roll-out; visual reference on runway and during taxi.
- Category IIIB: RVR less than 700 feet and down to 150 feet; no decision height established; need not use visual reference to stop; visual reference required to exit runway and during taxi.
- Category IIIC: No RVR or decision height restrictions established; need no visual reference to stop or to taxi; a fully automatic landing system.

Category III is currently in the research and development stage; the first phases of this category should be available for airline use by the early 1970's.

Pan American World Airways has specified that its fleet of Boeing 747's be certified and equipped for Category IIIA landing minimums on delivery in 1969. Five of Pan American's most recently delivered Boeing 707's are equipped to meet the requirements for Category II landings, and plans exist to equip all future purchases with this capability.

All but seven of the selected potential SST airports are presently scheduled for qualification as Category II airports. The airports not scheduled for Category II installations are: Dallas, Fort Worth, Honolulu, Miami, Phoenix, San Juan, and Tampa. Predictably very fine flying weather in the vicinity of these airports on a year-round basis overrides an economically supportable decision for Category II capability. Since much of the equipment required for Category II is common to Category III, it is logical to expect that those airports qualified for Category II will be the first to be upgraded to Category III.

(2) Ground Control

Airport Surface Detection Equipment (ASDE) will continue to be the radar system for monitoring ground traffic on airport runways, taxiways, and aprons until the introduction of Category III operations. Under Category III, various aids will be available to support all-weather operation on the airport surface. No visual reference will be required for ground movement during the advanced stages of Category III, which should be in use by the time an SST is in the air.

c. Effect of Increased Air Traffic on Potential SST Airports

There has been a significant amount of research into the elements of landing control, directed primarily to the determination of the effect of the SST on the requirements of ATC systems. Research has been conducted at the NASA-Langley Research Center and the FAA-National Aviation Facilities Experimental Center (NAFEC). Simulation of airport landing and departure demands subject to the introduction of various numbers of SST's per hour into a mix of subsonic traffic has provided insight into the problems associated with SST introduction. Dynamic simulation studies have permitted multi-variable analyses of delays as a function of air separation, climb and descent profile, and traffic control procedures, techniques, and concepts. Simulation of an SST high-priority concept (no restriction delays and/or holding) separate from the no-priority concept of current ATC procedures demonstrated

that preferential treatment of SST would impose excessive subsonic delays. Measurements were made of airport movements per hour, communications, subsonic aircraft delays, supersonic aircraft delays, and total SST time in the system. The value of this type of analysis and continued effort in the analyses of the delay elements of ATC become apparent in investigations of the implications of SST introduction.

Before a discussion of the cost to a user for ATC delay, a short description of the general problem and specific considerations associated with SST introduction are warranted. Primary emphasis in this discussion is on the specification of the factors of SST air traffic control in the terminal area which directly increase the costs to the user and indirectly impose social costs upon the public. The effect of air traffic congestion in terminal areas is obvious and of importance to the airline industry. Examination of historical trends in the growth of general aviation indicates that the demand for terminal control facilities by the general aircraft segment of itinerant aircraft is increasing at a rate in excess of the demand imposed by the airline industry. This historical growth pattern and the projected demand on the limited capacity of existing terminals has caused air carrier concern regarding the cost of congestion. Congestion is expressed quantitatively in terms of delays at take-off and landing.

Costs associated with delay and related to direct operations are more easily defined and computed than costs associated with missed connections and attendant inconvenience. It is obvious that the direct costs of delay, such as increased fuel consumption and increased flight personnel costs, are dependent on the type of equipment in service. The delay cost per unit time of a four-engine commercial passenger jet is substantially different from that for a four-engine piston airliner. It is reasonable to expect jet delay costs to exceed the hypothetical delay cost of any nominal aircraft representing the mix at air carrier airports considered for SST operation.

Air traffic control problems center around the derandomization of random aircraft arrivals into the terminal area. The term "arrival" refers to those aircraft landing and requiring control to ensure a desired landing interval, and additionally, to those aircraft arriving in a random sequence at the runway ready for departure. The ATC problem involves the formation of efficient arrangement of takeoffs and landings as influenced by, or as a function of, traffic demands, and the maximization of the total operation rate. Airport demand patterns are dependent on passenger preference and are expressed in activity peaks and troughs by hour during the day. The maximization of total operations can only be achieved by acting to reduce or minimize delays. The emphasis in terminal area air traffic operations rests with the landing flow process; specifically, the generation of accurate and reliable landing intervals with maximum traffic flow. Airborne aircraft have a higher fuel consumption rate than taxiing aircraft, as well as a finite fuel capacity. They are normally assigned priority over those aircraft awaiting takeoff.

There are four functional elements in landing control for all aircraft. Digital computer models have been developed to simulate the functions of buffering, regulating, funneling, and runway operations. The buffer element in ATC is involved in the vertical stacking of airborne arriving aircraft at 1,000-foot intervals within designated holding areas. The speed and path within holding areas of arriving aircraft are regulated. The spacing of the arriving aircraft occurs prior to their arrival at the outer marker. The regulating function achieves specific arrival spacing at the outer marker. The funneling function establishes actual separation for safe runway operations (a 3-mile or 1-minute separation is the present operational guideline). The runway operation element is principally concerned with runway occupancy. The constraints which dictate runway occupancy time are exit conditions, runway surface, wind condition, and time of day.

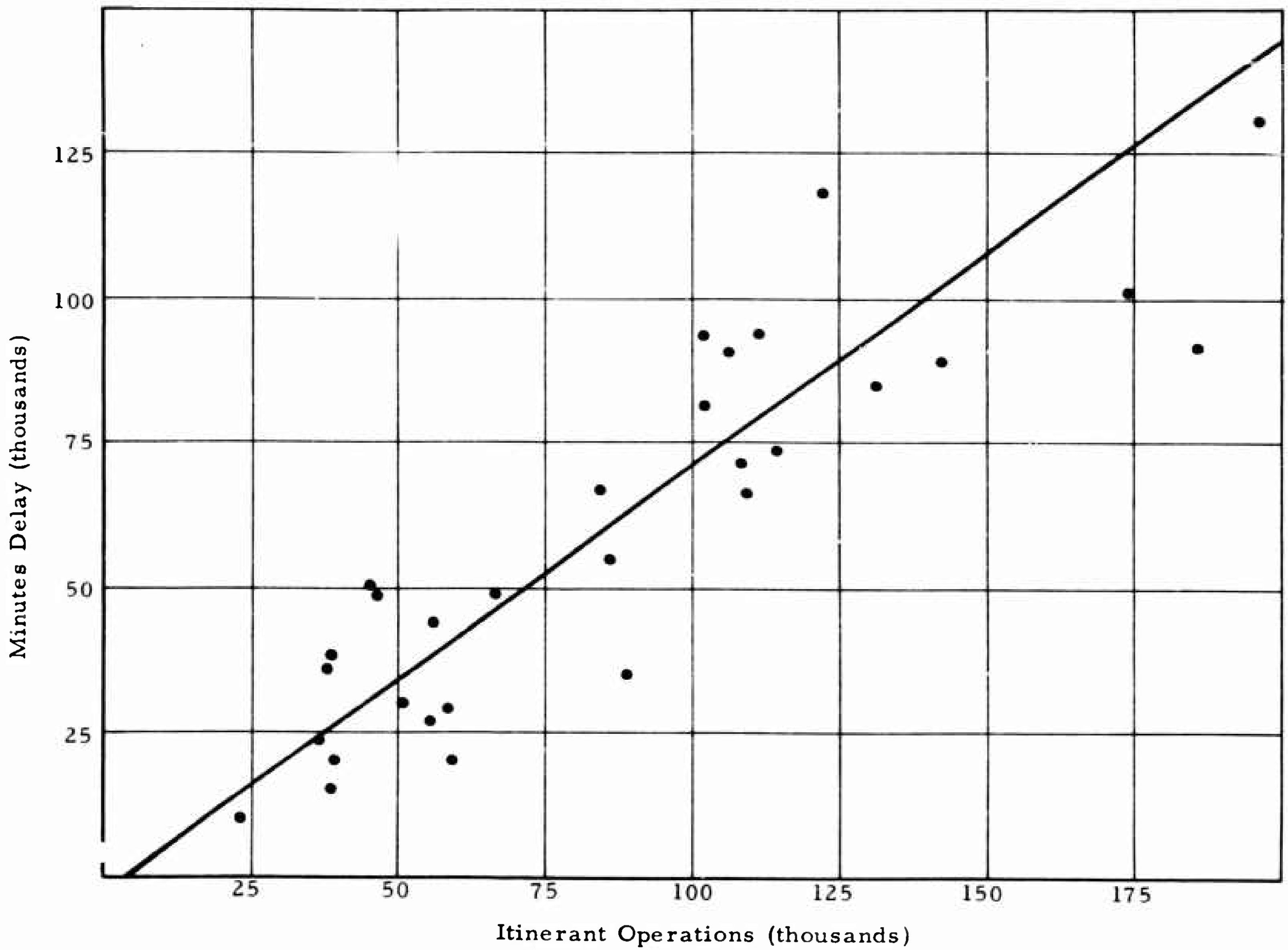
Various computerized techniques have been developed to simulate these four functions. The programs include queuing models, holding pattern models, laddering or stacking models, ILS funnel models, and

runway operation models. Various approach standards may be rapidly simulated and service and arrival rates and system utilization computed within these models when utilized as an integrated program. Since the SST is considered to be similar to existing jet aircraft in that no deviation from the standard traffic control standards is envisioned, the future ATC problem may be analyzed from the viewpoint of congestion due to the volume of activity.

Estimates of the cost of delay to the air carrier were developed by the Air Traffic Service of the FAA for the calendar year 1965.[1] Total minutes of delay were estimated based on United Air Lines experience at 47 airport facilities. The study demonstrated that delay times increased directly with itinerant aircraft operations. Exhibit 11 presents the resulting correlation of minutes of delay and itinerant operations. The correlation of .982 between delay and itinerant operations for the sample of airports was used. Approximately 40 percent of the delays in the study period were experienced by air carriers. Delay costs were calculated by United Air Lines based upon actual experience and projected by the FAA to represent all air carrier operations. Exhibit 12 illustrates the correlation of estimated delay costs and itinerant operations. The terminal delays included within this study represent both departure and arrival delays. Departure delays are composites of delays which may be attributed to surface traffic, taxi deviation over and under the standard, and air traffic control. Arrival delays are composed of delays associated with weather, ramp congestion, and air traffic control. Air traffic control delays were considered proportionally comparable not only for commercial aircraft but also for itinerant general and military aircraft.

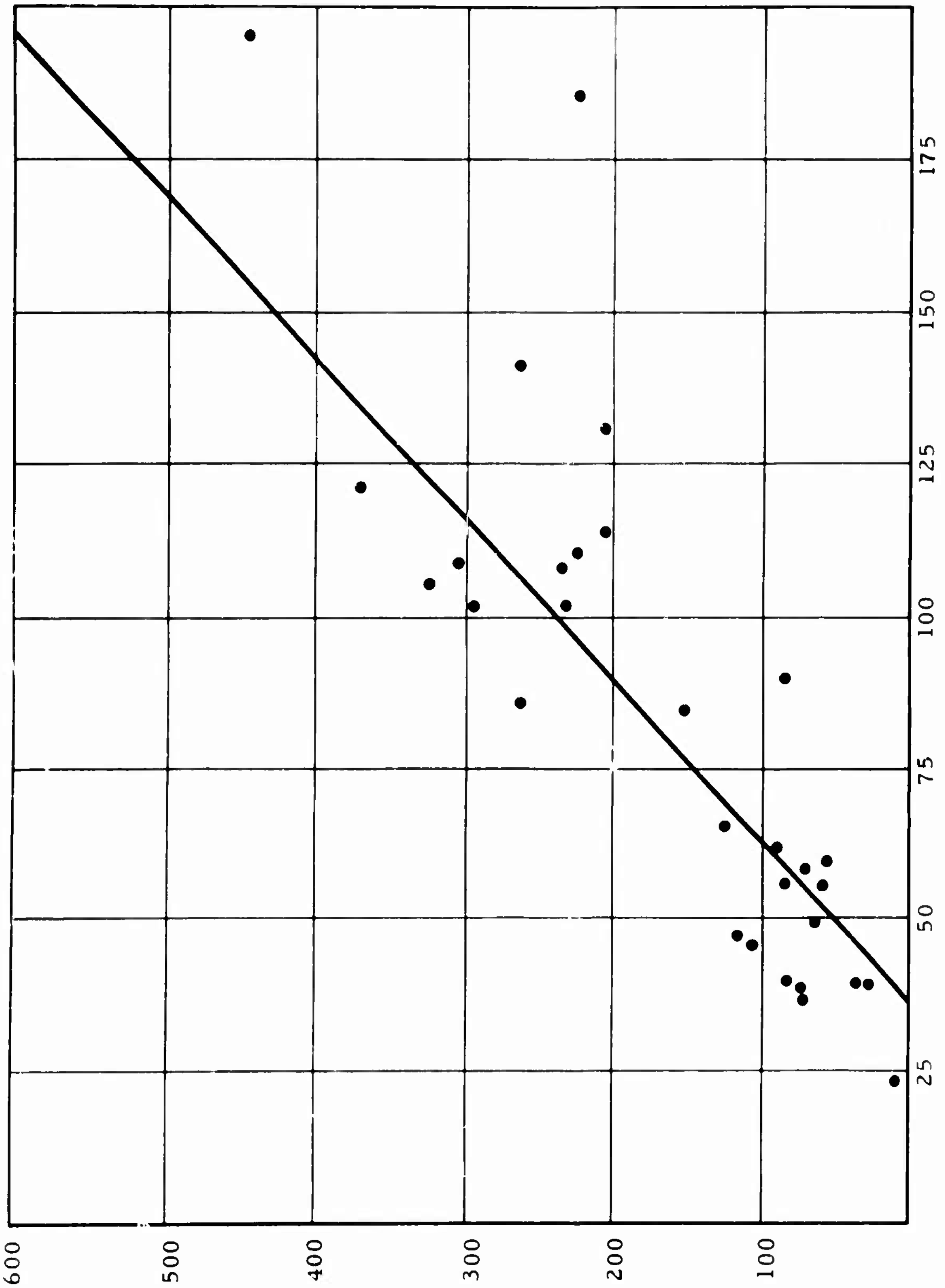
It was further assumed in the FAA study (which is the basis for the comparison presented) that airline fleet variation with respect to equipment types is roughly the same for all airports and all commercial airlines. Exhibit 13 presents the estimated delay time and cost extracted

[1] Federal Aviation Agency, Air Traffic Service, Staff Study, Estimated Cost of Delay at FAA Tower Airports FY 1965, June 1966



Source: (a) Federal Aviation Agency, Air Traffic Service, Staff Study, Estimated Cost of Delay at FAA Tower Airports FY 1965, June 1966

EXHIBIT 11 - CORRELATION OF MINUTES OF DELAY AND ITINERANT OPERATIONS



Source: (a) Federal Aviation Agency, Air Traffic Service, Staff Study, Estimated Cost of Delay at FAA Tower Airports FY 1965, June 1966

EXHIBIT 12 - CORRELATION OF ESTIMATED DELAY COSTS AND ITINERANT OPERATIONS

EXHIBIT 13 - ESTIMATED ATC DELAY COST COMPARISON

Airport	Itinerant Operations (per year)[a]	Estimated Total Air Carriers Delay (minutes)	Estimated Total Air Carriers Delay Costs ($000)[b]	Estimated Total Air Carrier Delay Cost for Nominal Aircraft ($/minute)	Estimated SST Delay Cost Factor (Applied to Nominal Aircraft Delay Cost) SST D.O.C./hr		
					$2800	$3200	$3600
Kennedy	373,143	1,030,302	6,618,825	6.42	7.3	8.3	9.03
O'Hare	483,385	775,364	6,221,832	8.02	5.6	6.7	7.5
Atlanta	244,655	390,458	1,343,866	4.34	11.1	12.3	13.8
Los Angeles	345,646	217,575	1,181,836	5.43	8.6	9.9	11.0
Boston	219,578	137,625	859,000	6.24	7.5	8.6	9.6
San Francisco	245,770	144,346	7,232,268	5.01	9.0	10.7	11.9
Philadelphia	204,586	131,093	610,842	4.66	9.7	11.5	12.8
Minneapolis	169,531	94,548	525,190	5.55	8.1	9.6	10.8
Cleveland	200,405	121,050	563,932	4.66	9.7	11.5	12.8
Portland	139,136	44,878	534,351	11.91	3.8	4.5	5.0
Miami	211,724	122,897	538,923	4.39	9.4	12.2	13.6
Honolulu	198,082	62,145	398,029	6.40	7.3	8.4	9.4
Denver	238,207	59,328	338,728	5.71	8.2	9.4	10.4
Kansas City	183,284	55,583	323,125	5.81	8.0	9.2	10.2
Pittsburgh	162,218	71,561	335,399	4.69	9.3	11.4	12.8

EXHIBIT 13 - (Continued)

Airport	Itinerant Operations (per year)(a)	Estimated Total Air Carriers Delay (minutes)	Estimated Total Air Carriers Delay Costs ($000)(b)	Estimated Total Air Carrier Delay Cost for Nominal Aircraft ($/minute)	Estimated SST Delay Cost Factor (Applied to Nominal Aircraft Delay Cost) SST D.O.C./hr		
					$2800	$3200	$3600
Detroit	157,348	56,915	262,184	4.61	9.9	11.6	13.0
New Orleans	102,493	47,269	273,154	5.78	8.1	9.3	10.4
Baltimore	134,325	42,580	179,361	4.21	9.0	12.7	14.1
Seattle	82,938	37,464	231,826	6.19	7.5	8.6	8.7
Tampa	105,080	46,544	187,367	4.03	8.6	13.3	15.0

Note: (1) Costs are presented in 1965 dollars.

Sources: (a) Federal Aviation Agency, Terminal Area Air Traffic Relationship, FY 1965

(b) Federal Aviation Agency, Staff Study, Estimated Cost of Delay at FAA Tower Airports, FY 1965

from the study in question for those airports considered as potential SST facilities. Column 4 presents the computed total air carrier delay cost per hour for a nominal aircraft representation of the aircraft mix estimated for the total industry, based on the United Air Lines sample. The point of this discussion is the cost of delay which may be experienced by the SST as it is introduced into the mix of aircraft requiring the use of the airport control facilities. Column 4 is the calculated delay cost per hour and may be regarded as the cost resulting from air traffic control delays. Assuming that the SST will conform to existing separation policy and general terminal area procedures, the problem is reduced to computation of the cost of current airline delays and estimations of factor increases in delay cost over the nominal aircraft dollars-per-hour cost as shown in Column 5. Estimates for SST delay costs were $2,800, $3,200, and $3,600 per hour. These costs were derived from estimates of the direct operating costs for the SST. The weighted average of all delay costs of $6.16 per minute in the 1965 sample may be compared with the SST anticipated delay cost of $53 a minute.

2. <u>Conceptual Systems: Navigation and Communication Satellites</u>

Particularly attractive for transoceanic flights are navigation and communication satellites possessing an ability to provide information independent of ground stations within radio range of the aircraft. High-frequency radio (HF), while effective for long-range communication, cannot be considered a reliable all-weather system because of propagation anomalies. Large communication gaps exist over heavily traveled North Atlantic routes where it is possible for aircraft to lose contact with control facilities for periods up to half an hour (depending upon atmospheric conditions). Lateral separation standards in the North Atlantic Region are based on the possible exceptions from accuracy to which an aircraft is subject by present navigational

methods. If a more reliable and accurate position determination technique (such as a navigational satellite network) becomes available, its use combined with a continuously reliable ability to transmit this position will make possible significant reductions in separation standards.

Discussions have been held between Comsat Corporation and the FAA to explore the use of satellites for aeronautical communication. Comsat proposed a system using a synchronous satellite over the North Atlantic to provide air-ground communication at a cost of approximately $20 million.[1] Such a system could be operational within 18-24 months after order. Although there is much enthusiasm for this program, several technical, political, and economic questions have arisen. Indications are that the FAA will defer a decision to implement this program until results of the ATS-B tests are available.

In September 1964, the Joint Navigation Satellite Committee (JNSC) was formed to determine possible aviation and maritime requirements for use of satellites in the areas of navigation and communication. The committee is composed of representatives from the Departments of Commerce, Defense, Interior, and Treasury, the Federal Aviation Agency, and the National Aeronautics and Space Administration.[2] Results of the ATS-B feasibility tests, combined with JNSC recommendations, should provide the basic formulation of a system plan. A satellite system for communications and position reporting is a practicable solution to the long-range over-ocean communications problem, as well as to problems associated with air traffic control.

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[1] Anonymous, "FAA to Defer Program with COMSAT," Aviation Week and Space Technology, June 27, 1966, p.46

[2] National Aeronautics and Space Administration, Astronautics and Aeronautics, Navigation Satellites for Worldwide Traffic Control, Eugene Ehrlich, December, 1965

A navigation/communication satellite system proposed for the North Atlantic Region[1] would be composed of two synchronous satellites placed at approximately 10 to 15 degrees and 50 to 70 degrees west longitude. This configuration would be capable of providing continuous all-weather position data at the predicted 1975 load of 8,000 to 15,000 fixes per hour, while continuing to satisfy communication requirements for the same period. Primary disadvantages of the dual synchronous satellite approach are the lack of polar coverage in the 75°-90° latitude region and the limited equatorial coverage below 10° north latitude. The placement of a satellite in a medium altitude polar orbit would correct this problem, but the polar traffic demand may not warrant such a solution. A proposed configuration utilizing six satellites placed at synchronous altitudes around the equator in 60° longitudinal increments could provide global coverage.[1] This system would also provide limited coverage in polar and equator areas.

The system incorporating synchronous altitude or geo-stationary satellites seems to merit special consideration. The first test of the feasibility of two-way ground-to-air voice communication by satellite is scheduled for late 1966 or early 1967. This satellite, Advanced Technology Satellite (ATS-B),[2] placed in a synchronous orbit over the Pacific Ocean, will be equipped with a VHF transponder. Two hundred watts of effective radiated power will be available, ensuring a positive signal-to-noise ratio which should permit voice communication and other tests related to an integrated air traffic control system. A series of tests was conducted in 1964 by Pan American World Airways to evaluate the transmittal of teletypewriter data by use of SYNCOM 3.[3] Results of these tests indicated a need for an R&D satellite for use in

[1] System Sciences Corporation, Selected Navigation and Communication System Concepts for 1975, April 1966, (prepared for Space Application Programs Office, NASA Headquarters)

[2] "ATS Aid Airline Communication Tests," Aviation Week and Space Technology, August 9, 1965, p. 117

[3] "An International Airline Views Navigation Satellites, Navigation," Journal of the Institute of Navigation, Vol. 13, No. 1, Spring 1966

the development of an operational system. The primary research effort to date has been directed toward the design of an antenna with omnidirectional capability. The ATS-B transponder will have more than 100 times the power of the SYNCOM 3 unit and will be operated using frequency modulation (FM) instead of the normal amplitude modulation (AM) for VHF air-ground communications. Use of FM techniques will provide a significant decibel gain in system performance.[1]

3. Satisfaction of Commercial Aviation Needs

No improvements to the system will be required by the introduction of the supersonic transport. Normal improvements programmed for institution by 1975 will be adequate to serve the vehicle in a safe and reliable manner. This does not eliminate the possibility of the need for special procedures under certain circumstances which could be identified and the procedures developed during the flight testing of the prototype aircraft.

These conclusions are valid only if there are no interruptions in the design and installation of the National Airspace System for the continental United States and the SPANAT recommendations for the North Atlantic. These two systems are evolutionary in nature and will provide the base on which further improvements can be made to accommodate increased amounts of traffic. The systems as now defined will provide efficient service to the air traffic expected to exist during the SST introductory period.

[1] "ATS Aid Airline Communication Tests," Aviation Week and Space Technology, August 9, 1965, p.117

VII. METEOROLOGY

A. Requirements of Commercial Aviation

The increasing number of aircraft in the skies, and the high-speed and altitude capabilities of the proposed supersonic transport place additional burdens on the various devices which collect, process, communicate, and forecast meteorological phenomena. These devices are currently being improved to meet the new demands for faster, more accurate, and more detailed weather forecasting imposed by the nature and number of aircraft using the skyways. Because the stretched and high-capacity subsonics will operate within the altitudes and speeds of existing subsonics, they present no unique demands on the present meteorological system. Normal planning and improvements will benefit these new aircraft, as well as the existing aircraft.

However, the basic design configuration and various subsystems of the SST, such as pressurization, navigation, propulsion, and cooling, involve a number of revolutionary concepts. The cruise portion of SST flight requires more accurate and more frequent coverage of the meteorological phenomena and parameters at high altitudes. Economic considerations of fuel consumption require accurate parameter profiles at the altitudes where transonic flight occurs. The high-speed capability of the SST makes preflight forecasting accuracy necessary because of the advance warning needed to maneuver.

B. Present Systems

1. Aviation Weather Service

The Analysis of National Aviation Meteorological Requirements through 1975[1] contains a detailed study of the current Aviation

[1] Borg-Warner Corporation, BRD-139, Analysis of National Aviation Meteorological Requirements through 1975, Eugene Bollay, et al., August 1961

Weather Service (see Exhibit 14). A systems approach is used, which coordinates all elements of the service--observation, communication, presentation, and processing of weather information.

a. Observation Subsystem

The ground observation system consists of 675 stations distributed as shown in Exhibit 15. At most of these stations, observations are made hourly, except in cases of rapid, significant weather changes. The 67 upper-air observation stations obtain measurements of temperature, wind velocity, pressure, and humidity every 12 hours; some of these stations make radio, wind, or ballon observations at the intermediate 6-hour intervals. Rawinsondes (special upper-air observation rocket soundings) provide information on wind temperature, pressure, and humidity to very high levels which are often above 100,000 feet. In addition to the 67 stations, upper-wind measurements by balloons are made at 79 other locations.

The radar weather observations made at a total of 102 locations (grossly distributed as shown in Exhibit 23) are extremely valuable in short-range forecasting. A special teletype circuit at Kansas City collects radar weather reports from the 98 radar systems in the east. An hourly summary is prepared and disseminated on Service A.[1]

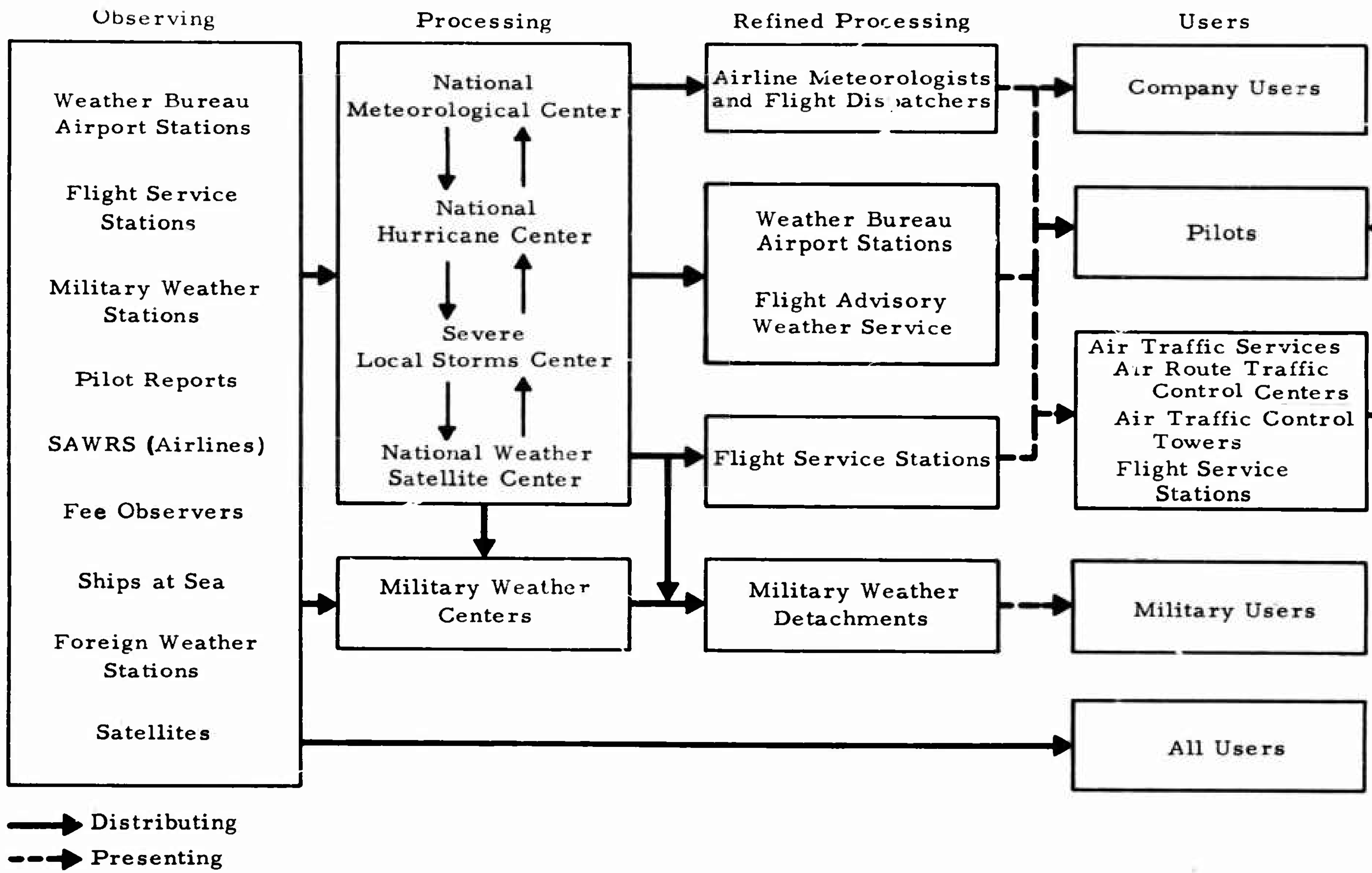
Further, enroute observations provide various important meteorological information such as that concerning icing, location and intensity of turbulence, wind speed and direction, and other factors.

b. Communications Subsystem

The communications subsystem utilizes four methods: teletypewriter, facsimile, radio, and telephone. Television is also being used experimentally.

The primary United States civil government systems used for distribution of aviation weather are Services A, O, and C, operated by the

[1] See subsection b.



Source: U.S. Department of Commerce, Weather Bureau and Federal Aviation Agency, <u>Aviation Weather</u>, 1965, p.159

EXHIBIT 14 - FUNCTIONAL DIAGRAM OF THE NATION'S WEATHER SYSTEM

EXHIBIT 15 - NUMBER AND KIND OF GROUND OBSERVATION STATIONS THROUGHOUT THE UNITED STATES

Weather Bureau Airport Stations	199
Automatic Meteorological Observing Stations	21
Federal Aviation Agency Stations	198
Joint Weather Bureau-Federal Aviation Agency Stations	14
Supplementary Aviation Weather Reporting Stations	133
Joint Weather Bureau-Supplementary Stations	9
Stations with part-time Weather Bureau employees	36
Navy and Marine Corps Air Stations	45
Air Force Air Bases	110
Weather Bureau Stations not located at airports	10
Total	675

Note: (1) Personnel certified by the Weather Bureau take additional observations at 108 other locations to legalize landings and takeoffs of commercial carriers. These observations are for local use only and are not transmitted.

Source: (a) Borg-Warner Corporation, BRD-139, Analysis of National Aviation Meteorological Requirements through 1975, Eugene Bollay, et al., August 1961

Federal Aviation Agency. Service A collects and distributes aviation operational information, predominantly information on the weather. Service O network transmits data to and from overseas points, and Service C transmits weather forecast information. Further, the Weather Bureau provides three special radar warning circuits for severe weather conditions, a special hurricane circuit, and additional local circuits located largely in the metropolitan areas.

The National Weather Facsimile Circuit has over 650 drops in the United States. Approximately 110 charts are transmitted each 24 hours. A special high-altitude facsimile circuit connects 23 aviation forecast centers and stations. Forecasts are distributed in graphic form and describe altitudes between approximately 18,000 and 45,000 feet. The products of all seven High-Altitude Forecast Centers together cover about two-thirds of the Northern Hemisphere. The Air Force and Navy also operate facsimile circuits oriented primarily to their respective areas of responsibility.

The Air Force operates three teletypewriter networks (COMET), each of which has eight circuits over which pilot reports and military weather observations are collected and distributed to military users as well as over the FAA circuits. Short-period terminal forecasts and hourly Aviation Weather Reports are collected over seven Air Force regional teletypewriter circuits. These are transmitted in a special format for direct input into the Semi-Automatic Ground Environment (SAGE) computers and displays of the Air Defense Command.

Although not exclusively a weather communications system, the worldwide U.S. Naval Communications System includes observed weather information such as area and severe storms, and high seas as part of the Navy's General Broadcast.

Continuous transcribed radio broadcasts are disseminated from 46 Weather Bureau Airport Stations and Flight Advisory Weather Service forecast centers over FAA L/MF navigational aids in the 200 to 400 KC band. The telephone communications involve a recorded message broadcast over a pilot's automatic telephone weather answering

service at 30 Weather Bureau Airport Stations and Flight Advisory Weather Service forecast centers. This service provides a 12-hour forecast of significant weather information within a 250-mile radius of the station. Miami International and Kennedy International airports are experimenting with closed-circuit television which links the briefing areas with the Flight Advisory Weather Service Station.

c. Presentation Subsystem

Both visual and aural flight information are presented to the various airspace users at Flight Service Stations, Weather Bureau Airport Stations, Ground Remote Areas, and in aircraft. Air Traffic Controllers and managers receive weather information at Airport Traffic Control Towers, Air Route Traffic Control Towers, Radar Approach Control Centers, and Flight Service Stations.

Pilots may receive continuous broadcasts of weather information for a radius of 250 miles over many of the low- and medium-frequency FAA navigation aids. The Pilot's Automatic Telephone Weather Answering Service operated by the Weather Bureau provides information similar to that of the continuous weather broadcasts. Person-to-person telephone briefings are provided by the Weather Bureau on both listed and unlisted telephone numbers. It is likely that briefing by closed-circuit television will be used more commonly in the aviation weather service of the future.

In-flight weather briefing services exist through the Flight Service Stations of the Federal Aviation Agency.

d. Processing Subsystem

The processing subsystem receives and processes observations. At each step in the processing function, the geographical coverage decreases, the detail in the information increases, and the period of validity narrows.

The National Meteorological Center (NMC) at Suitland, Maryland supplies a total of 140 products from its processing function. The Severe Local Storm Warning Center and the Hurricane Warning Centers

at Miami and San Francisco add to the NMC's products by furnishing specialized forecasts to the aviation meteorological processing subsystem.

The next step in the subsystem is the Guidance Forecast Center's processing of the NMC's analyses and prognosis. The United States is divided into eight regions for this purpose. These guidance forecasts cover smaller areas, but are still designed to assist meteorologists in preparing more detailed forecasts. The Flight Advisory Weather Service Forecast Centers further refine the data for aviation in general. One center is assigned to each of 25 areas.

The final step in the processing subsystem are the Weather Bureau Airport Stations. Forty-six stations and forecast centers prepare forecasts for continuous transcribed weather broadcasts. Currently, 350 airports receive terminal forecasts from these stations. The meteorological satellite program augments the observation function of the Aviation Weather Service. Exhibit 16 compares the relative capabilities and potential of aircraft and satellites.

2. Meteorological Satellites

The National Environmental Satellite Center (NESC) currently receives data from six satellites. Three of these, ESSA 1 and 2 and Nimbus 2, send extensive information. The other three are older satellites and send information intermittently. The Weather Bureau maintains approximately 15 receiving stations, the Air Force about 12, and the Navy about 3. Cloud pictures are sent out and received immediately as are some radiation data. Other data (such as temperatures of cloud tops) are stored on magnetic tapes which deposit this data at the Fairbanks, Alaska and Wallops, Virginia stations. Because of the rotation of the earth, the satellites pass these stations every 2 hours. The stored data they deposited is therefore 2 hours old at most when received at Fairbanks and Wallops stations.

Experimental balloons have successfully transmitted atmospheric temperature to the degree that mean temperatures have been

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EXHIBIT 16 - COMPARISON OF THE RELATIVE OBSERVATION CAPABILITIES OF METEOROLOGICAL SATELLITES AND WEATHER RECONNAISSANCE AIRCRAFT (NASA)

Relative Meteorological Observational Capabilities

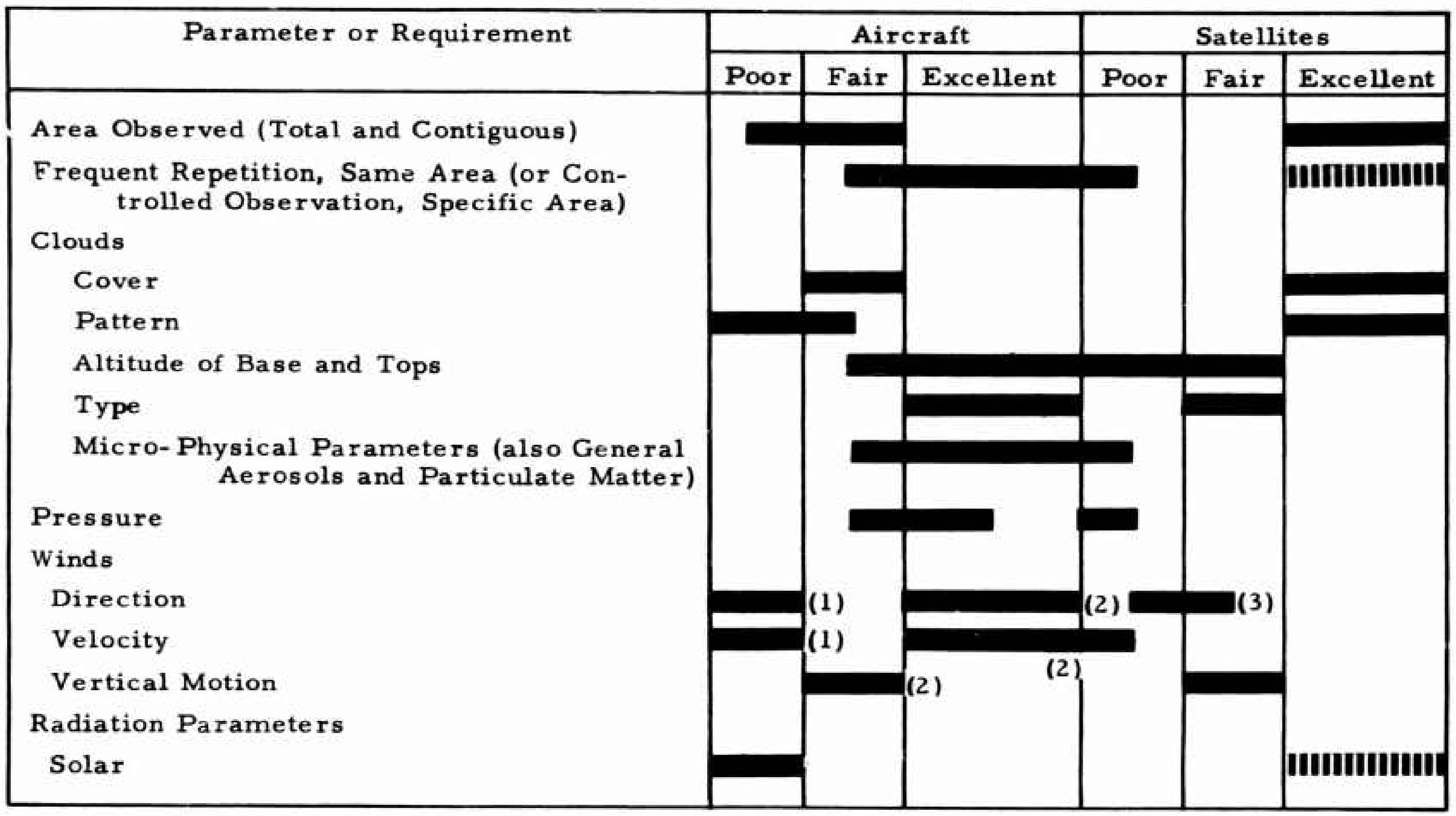

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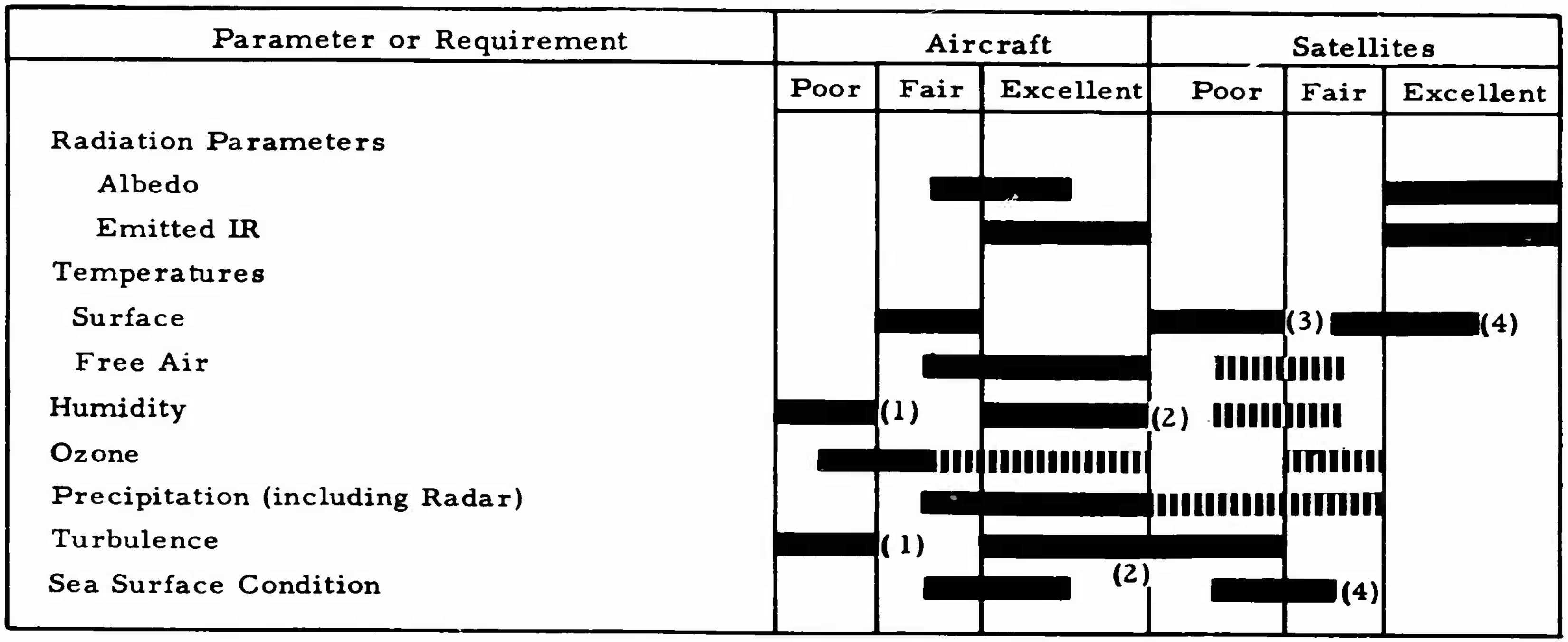
EXHIBIT 16 (Continued)



Notes: (1) Away from flight altitude
(2) Near flight altitude
(3) Clouds
(4) No clouds--unproven potential

Source: (a) Widger, William K., Meteorological Satellites. New York: Holt, Rinehart, and Winston, Inc., 1966

computed for each of five 2-mile layer segments of the atmosphere. Current temperature-sensing devices cannot collect data from any atmosphere lying below a cloud cover. Future research will be directed toward overcoming this limitation. These temperature-sensing devices have been used only in balloons to date. Present technology can detect precipitation and measure temperature in detail, but the cost of such observations is prohibitive at this time. Current stations receive cloud cover pictures, radiation data on five different channels, and temperatures of cloud tops. Plans to refine temperature data collection will be implemented within the next 18 months. The gathering of precipitation data from satellites is still experimental.

C. Adequacy of Present Systems

1. Stretched Subsonics and High-Capacity Subsonics

Stretched and high-capacity subsonic aircraft will require no unique improvements to the existing meteorological system. Several existing deficiencies should be corrected to improve the meteorological networks, however.

Borg-Warner[1] recently undertook a 2-year study to identify the weather information required for national aviation operations through 1975. The major conclusions concern three existing deficiencies in current subsonic operations. The two other deficiencies are considered as requirements of the Concorde and SST.

The following methods of improving the current subsonic weather system were suggested. First, the meteorological products of the aviation weather service should be of a nature that can be immediately used for operational decisions without further interpretation. This suggestion evolves from findings that objective weather observations were not always received by the processing subsystem, and that methods for processing these observations could not always provide operationally useful products. Secondly, the observation grid should be

[1] Borg-Warner Corporation, BRD-139, Analysis of National Aviation Meteorological Requirements through 1975, Eugene Bollay et al., August 1961

reduced, particularly in the Pacific Ocean, to ensure that all phenomena (including such local occurrences as squalls, icing, and severe to extreme turbulence) are reported for immediate use. (Also, the Weather Bureau suggests that additional ground weather radar observation stations be provided, particularly in the western United States, to complete the observation network.) Third, smaller airports that frequently lack instrumented weather observations should be provided with instrumentation. Approximately 800 civil airfields currently make and disseminate terminal observations. No instrumentation is available at some 3,000 smaller airports used by general aviation pilots.

Finally, objective methods of measuring icing and turbulence should be developed to eliminate inaccuracy or inconsistency because of differing types and speeds of aircraft and varying pilot experiences. Such inaccuracy and inconsistency results in a lack of standardized reports. Improvements in methods of measuring wind speed and direction, cloud heights, and visibility should be sought.

The existing FAA Weather communications Networks (A, C and O) have several drawbacks:

- <u>Selectivity</u>

  Receiving stations are supplied information which they do not need; only 50 to 60 percent of the received information is utilized.

- <u>Volume</u>

  The existing system has 300 circuits, and is estimated to be 30 percent overloaded. Thus, some 90 additional circuits are needed currently. Additional or special requests cannot be granted because of the mechanical difficulty in switching wiring, and because the circuits are so loaded that the addition of information to one circuit would mean the deletion of information elsewhere.

- <u>Speed</u>

  The increase in the number of subsonic aircraft in commercial service places a demand on the communication system for

more data to be transmitted more rapidly. The existing system provides little extra time for special forecasts or observations which are particularly necessary in periods of bad weather.

2. Concorde and SST

The present network needs improvement for commercial SST operation. Commercial supersonic high-altitude aircraft require detailed upper-air observations and rapid communications, along with detailed terminal area forecasts. The two Borg-Warner recommendations[1] applicable to Concorde and SST operations demand improved detail and increased altitude for the parameters observed.

As previously discussed, the ambient temperature profile through which the SST passes while in its transonic flight phase is a critical factor because of the great degree to which temperature influences SST performance during this portion of the flight. Increase in the detail and accuracy of forecasts, particularly in and around terminal areas, would significantly aid Concorde and SST flight. It is further stated that where radar is not currently available at potential SST terminals it should be provided, and where it does exist, it should be upgraded.

The last improvement necessitated by high-altitude flights is the collection of high-altitude data. Preliminary Weather Bureau estimates of meteorological support for SST operation utilizing any configuration of Ocean Station Vessels approach a prohibitively high figure. (This is presented in subsection E, below). It is consequently suggested that alternative means for providing meteorological support be investigated. One of these means might be airborne support in the form of satellites, rocketsondes, onboard aircraft equipment and the like, capable of "direct interrogation from the ground[2]." This,

[1] Borg-Warner Corporation, BRD-139, Analysis of National Aviation Meteorological Requirements through 1975, Eugene Bollay et al., August 1961

[2] Memorandum of 8 December 1965 from M. Fechter, Director, Weather Bureau Systems Development Office to G. Baughman of the SST Project, Department of Commerce.

together with increased data from land-based upper-air stations and with the provision of several ocean station vessels reporting from the truly data-sparse ocean areas, considerably lowers the amount of capital needed as well as the operating costs.

D. Future Systems

1. Expression of Need

a. Turbulence Data

Air Force experience with high-altitude flights indicates that turbulence does, in fact, occur at altitudes over 40,000 feet to the degree that it must be considered in SST operations. A recent Department of Commerce study states that in Air Force flights pilots involved in high clear air turbulence research experienced 10 hours of significant turbulence out of 98 flight hours over Puerto Rico. Further, Weather Bureau studies of U-2 data showed that 25 percent of the flights between 60,000 and 70,000 feet experienced moderate or greater turbulence.

Although data seems to indicate that the SST will be responsive to gusts of greater wavelength than those experienced by the U-2 aircraft, data on the complete turbulence spectrum is necessary. Research into methods of detecting turbulence (particularly that which occurs in clear air) should be continued.

b. Temperature Data

Research indicates that temperature will be a critical consideration in the economic operation of the supersonic transport. Nelms concludes from his study of the effects of atmospheric temperature variations on SST performance[1] that performance associated with hot-day conditions will be of greater consequence to the SST flight crew than to that of current subsonic jet transportation aircraft. He states further:

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[1]National Aeronautics and Space Administration, NASA TM X-54, 040, Some Effects of Atmospheric Temperature Variations on Performance of the Supersonic Transport, Nelms, Walter P., March 1964, p. 12

"Because of the severe losses in performance as a result of increased temperature during certain phases of the mission, the operators will need more frequent and accurate temperature information than that which is supplied today, particularly in and around the terminal areas."

A subsequent document,[1] reporting the results of further research into the effect of ambient temperature on SST performance, states that off-design operation (due to hot-day conditions causing a reduction in Mach number) can increase the amount of fuel used during the cruise portion of flight by as much as 10 percent.

"This increase in fuel will approximately double the total effect of temperature on fuel used as compared to the results presented in Nelm's paper."[2]

Further, the support panel document stresses the importance of pre-flight forecasting accuracy and flight planning.

A Hughes Aircraft study considered the operating economics of the SST as influenced by route temperature. In a flight simulation using a fixed geometry canard-delta airframe designed for Mach 3.0 flight, and taking into account a hypothetical aircraft configuration, weight, and atmospheric conditions, the Hughes program evaluated the effects on the SST flight profile of flying directly through an area of hot-day conditions.

"A simulation of the aircraft encountering a 30° hot atmosphere at optimum standard-day cruise conditions at Mach 3.0 shows the flight profile would require only minor altitude changes to reach the new optimum altitude for the non-standard conditions."[3]

Exhibit 17 shows the effect of temperature gradient on Mach 3.0 optimum cruise altitude for a constant nominal cruise gross weight.

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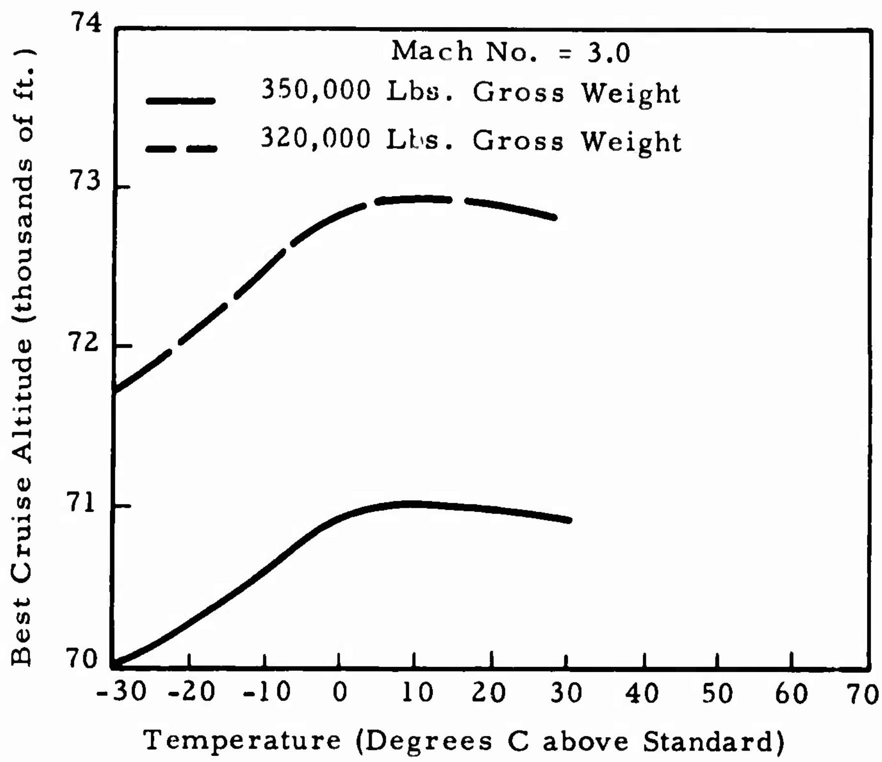
[1] Supporting Report of Panel on Meteorological Problems of Supersonic Aircraft to Aviation SC/ICMS, Some Meteorological Considerations of the SSA Temperature Environment, 15 October 1965

[2] Credit within Supporting Report of Panel on Meteorological Problems of Supersonic Aircraft given to Mr. Joe Stickle of National Aeronautics and Space Administration, Langley Space Center

[3] Hughes Aircraft Company, The Influence of Route Temperature Effects on SST Navigation, Fuel Management, and Operating Economics, D. W. Richardson, et al., June 1964



Source: (a) Hughes Aircraft Company, The Influence of Route Temperature Effects on SST Navigation, Fuel Management and Operating Economics, D. W. Richardson et al., 1964

EXHIBIT 17 - EFFECT OF TEMPERATURE ON CRUISE ALTITUDE

The simulation revealed that the increase in temperatures[1] investigated resulted in an increase in overall fuel consumption and a decrease in total mission time. It was further revealed that if the nonstandard temperature conditions could be restricted only to the cruise portion of flight, the overall effects of the pertinent parameters of the flight would be small, although not inconsequential.

However, it was found that if the SST were operated in a region of elevated temperatures during the climb and acceleration phase, the overall fuel consumption would be greatly increased, the maximum thrust would be decreased because of elevated temperatures, and the performance of the aircraft would deteriorate markedly. Exhibit 18 illustrates the above effects in addition to the various other results of the flight simulation.

The study concluded that direct operating cost (DOC) and fuel consumption would be significantly affected by temperature gradients experienced in supersonic climb and acceleration, while these parameters would be only mildly affected by nonstandard operation when restricted to the cruise portion of the flight. It was noted that unacceptable penalties in DOC and total fuel consumption result when the SST is constrained by total temperature limitations.

Therefore, reliable meteorological data on temperatures, particularly in the climb and acceleration regions, must be available to allow serious consideration in preflight planning.

Again it is emphasized that a lack of upper-air temperature data over parts of the world must be corrected. Additional ground observation stations as well as more frequent upper-air observations can correct the deficiency. Planning for long-range upper-air temperature forecasts and more precise climatology route manuals, in addition to more reliable short-term and spot predictions will significantly facilitate more accurate and economical flight planning.

[1](Temperature = 15°C, + 30°C during cruise.)

EXHIBIT 18- EFFECT OF VARYING AMBIENT TEMPERATURES ON SST FUEL CONSUMPTION, TIME, AND DIRECT OPERATING COST

Type of Flight	Cruise Mach No.	Initial Cruise Alt. at Start of Hot Cruise (ft.)	Final Cruise Alt. (ft.)	Total Fuel (lbs.)	Total Time (hr./min./sec.)	Total Direct Operating Cost ($/mi.)
Standard-day takeoff and cruise: 750 n. mi. +15°C hot-day cruise: 1,500 n. mi. Standard-day cruise: 750 n. mi. and descent	3.0	70,000	73,900	165,687	2/15/55.1	2.816
Same as above except +30°C cruise: 1,500 n. mi.	3.0	69,800	73,800	168,236	2/15/0.7	2.822
+15°C hot-day climb cruise: 750 n. mi. Standard-day cruise and descent: 2,250 n. mi.	3.0	69,558(1)	75,295	170,644	2/20/14	2.895
Same as above except +30°C hot-day climb and cruise: 750 n. mi.	3.0	71,500	76,257	184,170	2/27/34	3.064
Same as above except standard-day up to 36,089 ft. and inversion ending at +30°C at 80,000 ft. on climb and cruise: 750 n. mi.	3.0	69,750	75,082	168,058	2/17/32.4	2.851

EXHIBIT 18 (Continued)

Type of Flight	Cruise Mach No.	Initial Cruise Alt. at Start of Hot Cruise (ft.)	Final Cruise Alt. (ft.)	Total Fuel (lbs.)	Total Time (hr./min./sec.)	Total Direct Operating Cost ($/mi.)
Same as above except -30°C day up to 36,089 ft. and inversion ending at standard-day at 80,000 ft. on climb and cruise: 750 n. mi.	3.0	69,260	74,539	160,157	2/15/34.5	2.779

Note: (1) At start of std. cruise

Source: (a) Hughes Aircraft Company, The Influence of Route Temperature Effects on SST Navigation, Fuel Management and Operating Economics, D. W. Richardson, et al., June 1964

c. Jet Stream and Wind Shear Data

(1) Jet Streams

The FAUSST[1] meeting of June 1964 identified a data deficiency in respect to the incidence and intensity of jet streams above 40,000 feet. In spite of the fact that the jet stream may shift position daily, patterns have been identified which facilitate its forecasting.

Special upper-air observation stations employing electronic devices to track the flight of a free balloon ascending into the atmosphere are usually spaced "well in excess of several hundred miles" apart.[2] For this reason, it is possible for a jet stream to lie between adjacent stations and not be evident from their reports. Additional stations would contribute quantitatively to the improvement of the observations.

In addition to its effect upon the revenue-producing factors of payload and range, the jet stream has been found to be associated with clear air turbulence.[3] This turbulence is believed to be caused by the shearing effect of adjacent air currents moving at different speeds. Research should continue to explore the specific nature and extent of this relationship.

(2) Wind Shear Data

Because of its accompanying turbulence, a consideration of wind shear is important in SST flight planning as well as in planning for all other aircraft in the sky. An extreme form of wind shear associated with strong temperature inversions near the ground[4] is a potential hazard to aircraft immediately after takeoff or on the final approach for landing.

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[1] FAUSST is a working group of Weather Bureau and FAA personnel and their British and French counterparts.

[2] U.S. Department of Commerce, Weather Bureau, GPO 904-285, The Jet Stream: A Band of Very Fast Winds Found at High Altitudes

[3] Eastern Air Lines, Inc., Meteorology Department Cwb-10674, A Study of Flight Conditions Associated with Jet Stream Cirrus, Atmospheric Temperature Change, and Wind Shear Turbulence, Paul Kadlec, June 1964

[4] U.S. Department of Commerce, Weather Bureau, GPO 927515, Turbulence . . . Its Causes and Effects

Crutcher[1] states that current atmospheric motion detection balloons are not sufficiently high and that rocket data are not sufficiently low as yet to produce adequate information in the layer between 50,000 and 100,000 feet. In June 1964, FAUSST identified a need for increased magnitude and extent of vertical and horizontal wind shear data.

d. Ozone

Some individuals are sensitive to ozone when there is 1 molecule in 25 million molecules of air. When ozone concentration reaches 1 part in 2 million, the nose, throat, and air passages are irritated. Increase of the concentration to about 10 parts per million may cause sickness.[1]

A 1963 ozone measurement survey[2] in commercial jet aircraft detected appreciable quantities of ozone during some of the flights investigated. This report concluded that the ozone concentration varies with altitude, latitude, and season. Internal ozone concentration on flights below the tropopause (Exhibit 19) was found to be negligible. The ozone-enriched masses were located and identified as segments of the lower stratosphere. Therefore, those routes which are consistently flown above the tropopause[3] will have a higher-than-average ozone exposure (see Exhibit 20). The SST will be one of these later aircraft.

Crutcher identifies the potential hazard to SST passengers and crew from higher-than-average concentrations of ozone in the air they breathe in flight.[1] He adds that small, light, and effective filters are available to destroy ozone in the air and offers this as a solution to the problem, whether the transport cabin is supplied with air from the outside or sealed and supplied with an artificial atmosphere.

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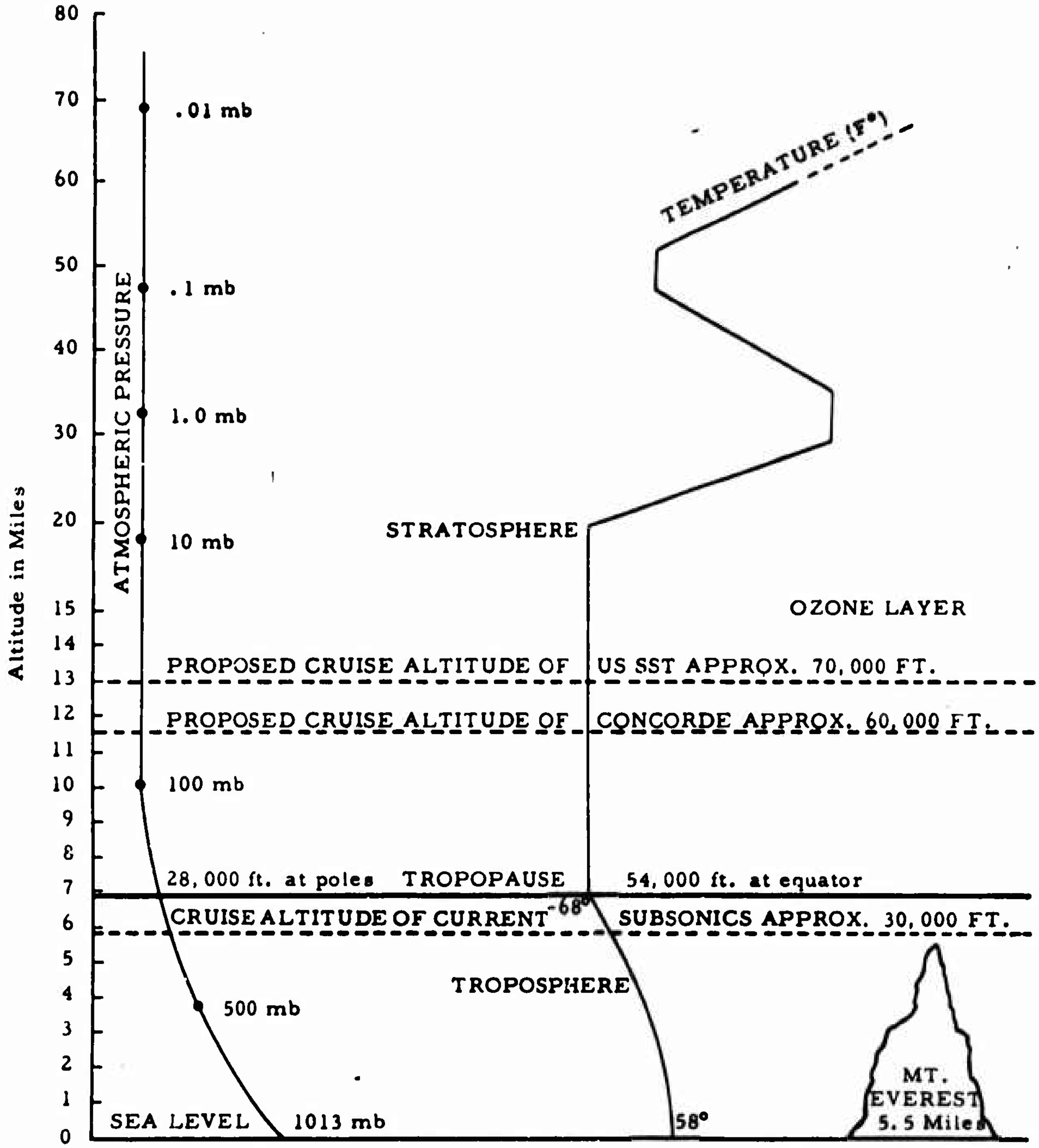
[1] U.S. Department of Commerce, Weather Bureau, Climatology of the Upper Air as Related to the Design and Operation of Supersonic Aircraft, Harold Crutcher

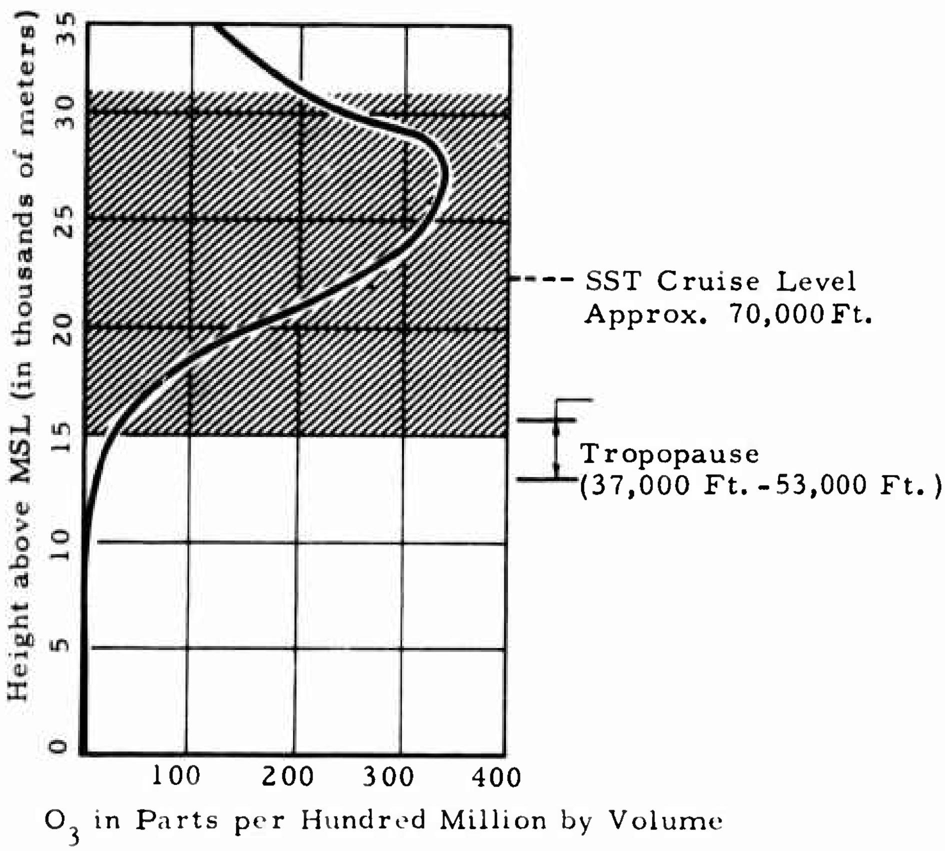
[2] Illinois Institute of Technology Research Institute Technical Report ADS-5 for Federal Aviation Agency, Robert Brabers, November 1963

[3] The region at the top of the troposphere, about 7 to 10 miles (37,000 to 53,000 feet) above the earth's surface.



Source: U.S. Department of Commerce, Weather Bureau, "Weather Forecasting", 1963

EXHIBIT 19- A SCHEMATIC CROSS SECTION OF THE ATMOSPHERE



Note: (1) Sounding taken at 1709 GCT on May 11, 1962 at Sterling, Virginia. Data furnished by Mr. W.D. Komhyr, Office of Meteorological Research, U.S. Weather Bureau, Washington, D.C.

Source: (a) U.S. Department of Commerce, Weather Bureau, Climatology of the Upper Air as Related to the Design and Operation of Supersonic Aircraft, H.L. Crutcher

EXHIBIT 20 - OZONE DISTRIBUTION IN PARTS PER HUNDRED MILLION BY VOLUME(1)

A report[1] issued by the Panel on Meteorological Problems of Supersonic Aircraft states that an onboard monitor with appropriate instrumentation will be required by supersonic aircraft. Controls will allow the crew to close packs delivering air with high ozone concentration as indicated by the instrument viewer. Thus, no requirement for forecasting the ozone content of ambient air is anticipated to satisfy the U.S. requirement for a maximum ozone content of .2 ppm inside the SST pressurized compartment.

e. Precipitation

One of the many problems which will affect the SST operation presents a serious hazard to its structural integrity. This problem arises from encounters at supersonic velocities with particulate matter which includes clouds, rains, and aerosols.

General Electric[2] reported supersonic aircraft penetration of clouds which resulted in considerable structural damage. External sensors were rendered inoperative or caused to malfunction and windshields, radomes, painted areas, and the leading edges of lift surfaces were damaged by erosion.

It was further found that aerosol content (dust, sand, rain droplets, etc.) has a serious effect on high-speed flight at low altitudes. This evidence indicates that the aerosol distribution in the region of transonic and supersonic speed should be known. In addition, probability of cloud occurrence at operational altitudes should be ascertained, composite particles identified, and particle size noted.

The following phenomena associated with clouds were identified in a report on the FAUSST meeting of June 1964 as areas in which research was needed to fill gaps in existing knowledge.

[1] Panel on Meteorological Problems of Supersonic Aircraft Report No. 3, March 1966

[2] General Electric Valley Forge Space Technology Center, GEN-10294, Particulate Matter and the Supersonic Transport, A. F. Petty, February 1963

(1) Hail

(a) The range and size of hailstones

(b) Their distribution in and around storms

(c) The frequency of encounter of various sizes of hailstones as a function of altitude for different geographical areas

(d) The extent of the area to be avoided if hail is detected by radar.

(2) Rain

(a) The intensity of rain at different altitudes and geographical areas and its frequency

(b) The range of raindrop sizes

(c) The maximum altitude at which rain can be encountered as a function of temperature, geographical area, and other related parameters.

(3) Ice Crystals

The question of possible erosion from ice crystals requires study. In addition, the possibility of ice formation due to ice crystals even at supersonic speed may have to be investigated. Ice crystals are not considered to present as difficult problems as rain or hail, however.

f. Sonic Boom

Although not a hazard in itself to supersonic flight, the sonic boom is an area for further study. FAUSST reports that sonic boom focusing can be caused by changes in wind field and temperature beneath the aircraft. Teweles and McInturff[1] state that along with wind and temperature, the effects of atmospheric pressure gradient and to a lesser extent humidity, cloud cover, and hydrometeors on the sonic boom necessitate the forecast of atmospheric conditions along and under the

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[1] World Meteorological Organization, Physical and Synoptic Meteorology in Relation to the Special Requirements of Supersonic Aircraft Operations, Sidney Teweles and Raymond McInturff, May 1966

flight path. They comment further that "in the vicinity of the transonic phase corridors, a particularly detailed forecast will have to be made."

SST cruise altitude will generally be far above the maximum wind level and, in general, shock waves will be greatly attenuated in moving into and through a level of maximum wind (see Exhibits 21 and 22). This reduces the chances of sonic boom damage by an SST in level unaccelerated straight flight at cruise altitudes.

However, it is the opinion of Teweles and McInturff that substantial changes in sonic boom intensity at the ground resulting from wind gradients and vertical temperature will not be observed unless the speed of the aircraft relative to the ground is no greater than the speed of sound at the ground.

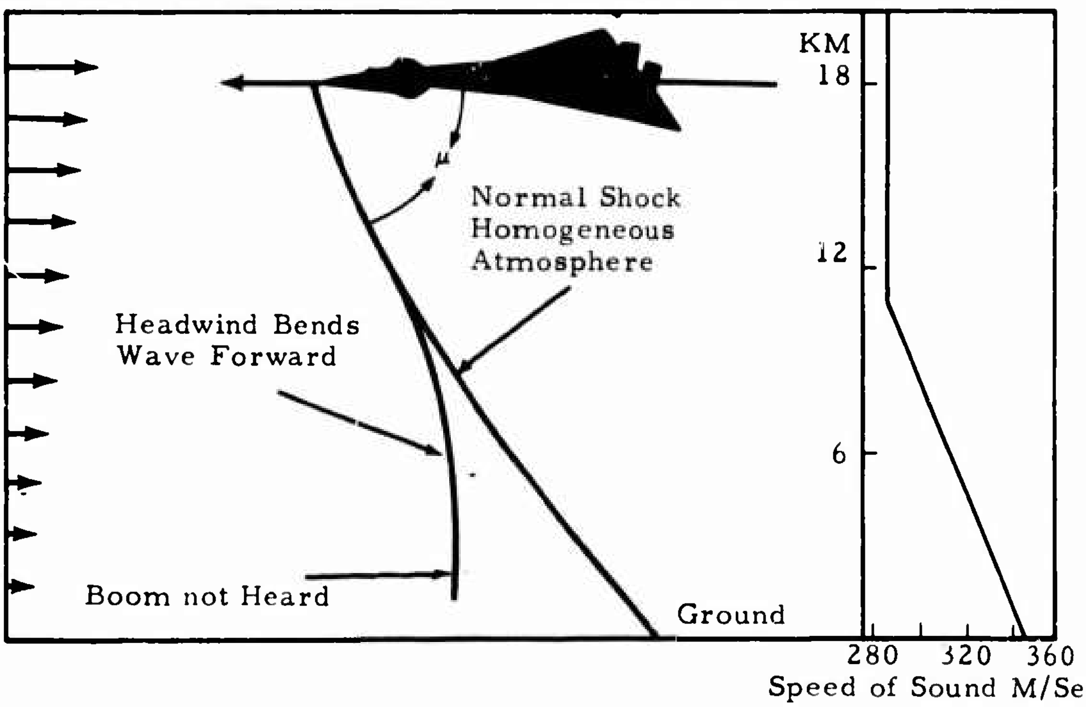
There is a need for further theoretical study and experimental flight testing to determine the relationship between sonic boom intensity and turbulence near the ground, aircraft maneuvers, buildings and topographical features, and sonic boom focusing under various conditions of atmospheric structure.

g. Other Needs

In addition to a requirement for collection of data on various meterological phenomena, several other needs are evident. Upper-air observations in the U. S. and eastern Europe quite regularly reach 80,000 to 100,000 feet. However, data collection from other parts of the world lacks regularity and accuracy above 50,000 feet. Additional stations are needed to close existing gaps in the observation system. Currently operating stations outside the U.S. and eastern Europe should upgrade their observing capabilities to ensure frequent and accurate coverage to 100,000 feet.

Exhibit 23 illustrates a lack of radar coverage in the western United States. Additional radar weather stations are needed to complete the U.S. observation network.

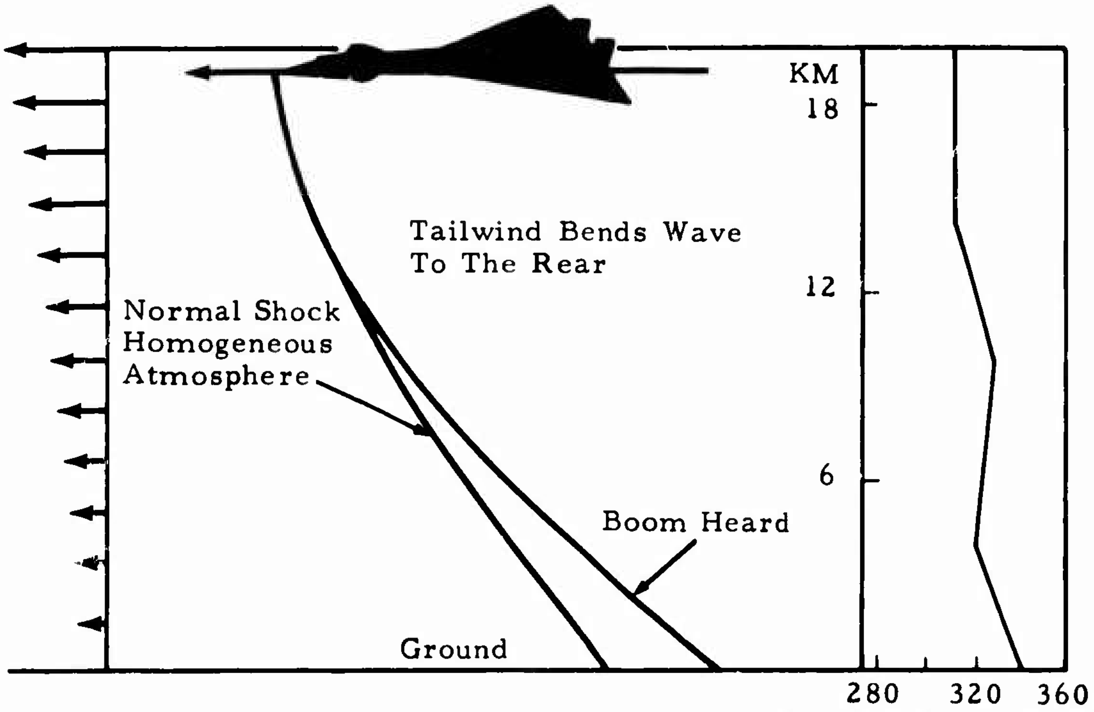
Borg-Warner Corporation specified a need in commercial aviation for more detailed terminal area forecasts. This is particularly important for large terminals where a single instrument may not be adequate to cover local variations. For example, at an airport where large horizontal gradients persist, a single sensing element is inadequate to measure temperature representatively.



Distortion of shock wave by headwind increasing with height and/or normal temperature lapse rate. The shock front is shown as bent forward until it is vertical and so cut off from the ground.

Source: Federal Aviation Agency, Some Considerations of Sonic Boom, Power, J.K., 1961

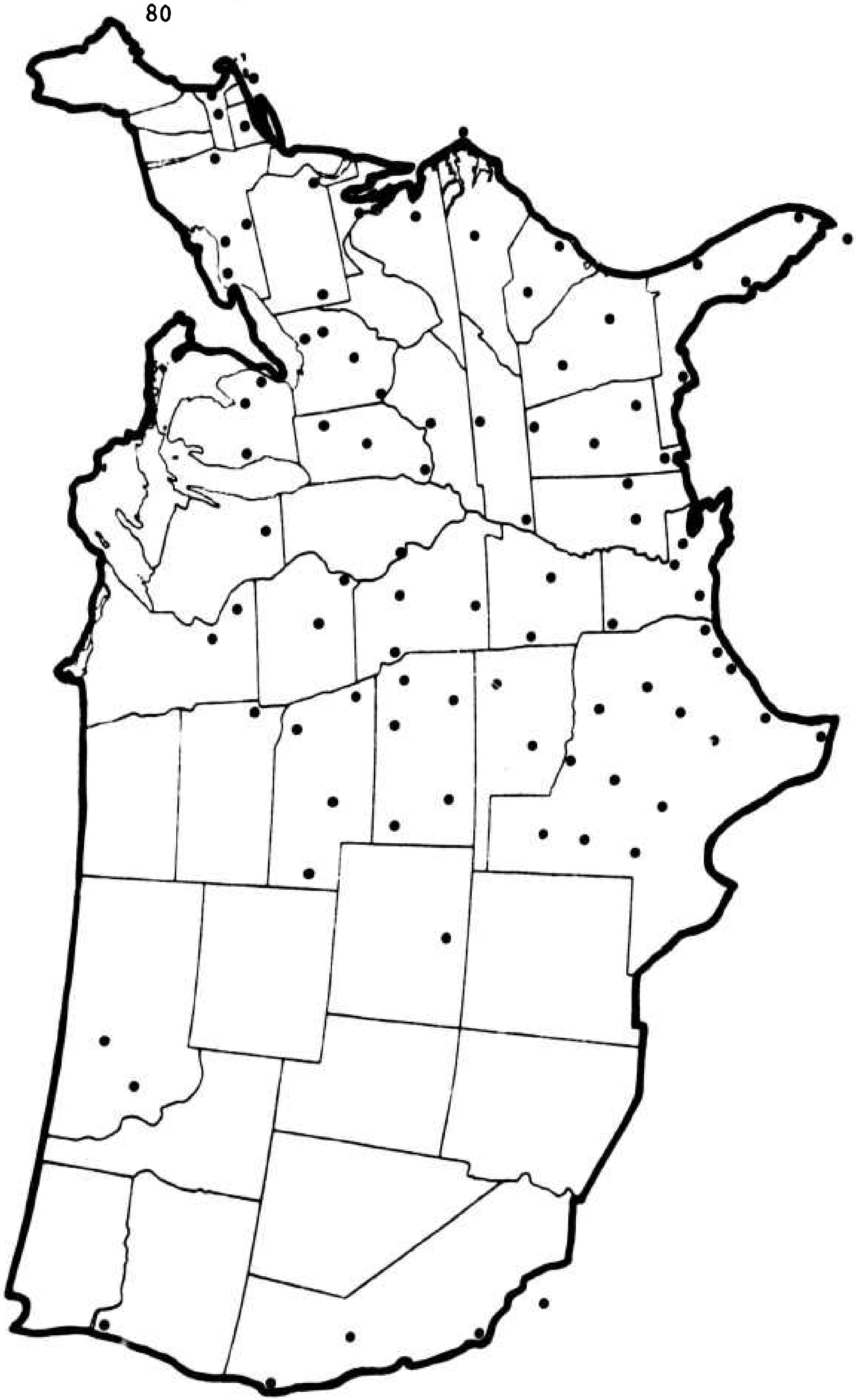
EXHIBIT 21 - EFFECT OF HEADWINDS ON SONIC BOOM



Distortion of shock wave by tailwind increasing with height and/or temperature inversion at lower levels. The shock wave tends to become more convex; the boom reaches the ground, but is attentuated as energy is dissipated over an expanding sector of the wave.

Source: Federal Aviation Agency, <u>Some Considerations of Sonic Boom,</u> Power, J.K., 1961

EXHIBIT 22 - EFFECT OF TAIL WINDS ON SONIC BOOM



Source: Federal Aviation Agency, Civil Aeronautics Board, <u>Aviation Weather</u>, 1965, p.178

EXHIBIT 23 - DISTRIBUTION OF RADAR WEATHER OBSERVATION STATIONS

2. Planned Successor Systems

a. Teletypewriter Communications

To help meet the need for rapid communications exchange, the FAA has proposed a teletypewriter communications system. This system design centralizes, consolidates, and automates the message switching functions of the existing weather teletypewriter Services A, O, and C within the Weather Message Switching Center.

The existing system has 300 circuits and is 30 percent overloaded, which means that 390 circuits are needed. If the proposed computerized system is operational in 1968, it will provide 150 percent of the present requirements, or 585 circuits. The proposed system has a potential for expansion to twice its 1968 capacity, or 1,170 circuits. Comparison of the possibility of 1,170 circuits with the present capability of 300 circuits yields a potential of almost 400 percent of present service networks. The Air Force maintains its own circuits (COMET) and receives information over FAA circuits as well. The computer would eliminate the redundancy of their receiving their own reports back. Annual operating expenses would decrease with use of the computer because of the shutdown or elimination of relay systems and the need for attendant personnel.

Along with the introduction of this National Weather Communications System Network, the FAA plans to commission the Aeronautical Fixed Telecommunications Network (AFTN), designed to replace message-switching functions now performed manually or by semiautomatic electronic equipment at New York City, Miami, San Juan, Puerto Rico, and Balboa, Canal Zone. Communications circuits between these cities and points in the Atlantic, the Caribbean, and in South America which now operate in the high-frequency radio range will be placed in submarine cables and extended by land lines to computers. Under this system, Kansas City will be the central point for routing of aeronautical and meteorological traffic between the United States and stations in the Caribbean. Although military and civil cooperation in use of the AFTN during times of emergency is expected, it will be funded entirely by the FAA.

b. Satellite

A promising solution to the deficiency of upper-air data collection is through the use of weather satellites. Temperature-sensing devices have been used only in balloons to date. Current devices cannot collect data from any atmosphere lying below a cloud cover. Future research will be directed toward overcoming this limitation.

Within the next 18 months, temperature-sensing devices will be sent aloft in satellites to test operating capabilities from higher altitudes, as well as to receive data on temperatures of the upper atmosphere. One such satellite program is the Apollo weather mission schedule. Tanks normally used for fuel in a moon flight will house men and equipment and the craft will orbit the earth in several test flights before the actual moon probe. Weather-measuring devices will be among the various equipments carried on the rocket, thus providing an excellent opportunity to test collection techniques as well as equipment.

Current commercial receiving stations cost approximately $30,000; however, a receiving station can be built for as little as $1,000. Current stations receive cloud cover pictures, radiation data on five different channels, and temperatures of cloud tops. Plans to refine temperature data collection will be implemented within the next 18 months and will include infrared cloud pictures taken at night. The gathering of precipitation data from satellites is still experimental.

One of the most important developments within the satellite program is that of a synchronous satellite to make possible continuous worldwide coverage. In the past, a satellite has rotated about the earth so that a given location on the earth's surface is observed once for each orbit of the satellite. The time between observations has depended on the rapidity with which the satellite circled the earth. The synchronous satellite has an orbit speed matched to the rotation speed of the earth, so that it observes continuously the same point on the earth's surface. In this way weather movements can be more accurately predicted and more rapidly reported.

c. World Weather Watch[1]

Today, in any 24-hour period, about 100,000 surface weather observations and 11,000 upper-air observations are recorded at some 8,000 land stations, 3,000 transport and reconnaissance aircraft, and 4,000 merchant ships around the world. The methods of collecting pressure, temperature, humidity, visibility, clouds, etc., conform to internationally agreed-on practices. A network of national, regional, and continental centers collects and retransmits information which is used for maps generally produced at 6-hour intervals. The existing meteorological telecommunications system works to ensure prompt collection and dissemination of the basic weather data.

The term "World Weather Watch" is the name given to a new world weather system which the World Meteorological Organization (WMO) is now planning. Recent developments in technology such as computers and satellites require more than simple readjustments in the existing worldwide systems. The various components of the system must be analyzed so that it will utilize the scientific advances in the most efficient manner. Plans for the World Weather Watch which are now being prepared may be divided into three broad categories: Global Observational System, Global Telecommunications System, and World Weather Watch centers of various kinds.

The development of a Global Observational System will be approached in several ways. Conventional ocean observations will be increased in number and their altitude coverage will be expanded by the introduction of radiosonde observations. Satellite coverage, special aircraft reconnaissance flights, and the use of dropsondes-radiosondes which transmit observations as they parachute after release from an aircraft will further add to global observations. Many techniques are still experimental, and the final working mixture of the devices will depend on the cost and efficiency of each type in different parts of the world.

[1] World Meteorological Organization, No. 183, TP 92, World Weather Watch, 1966

The planned Global Telecommunication System is based on a high-speed circuit called the "main trunk circuit" which will connect the three World Meteorological Centers. A number of Regional and National Meteorological Centers will be linked directly to the main trunk circuit. In designing the system, the fullest possible use will therefore be made of cable and land-line circuits or other telecommunication methods with similar technical and operational characteristics.

Current developments in satellite technology will result in significant improvements, of which one will be satellite interrogation of unmanned weather stations, buoys, and floating balloons. These will in turn be read out to selected ground command stations or broadcast for reception by a number of stations. Although these new techniques will not be available during the initial stages of the World Weather Watch, they will undoubtedly take their place once their full potential has been established.

To collect and process the wealth of material obtained from the new system, complex and costly equipment will be needed. A logical solution to this problem is the establishment of a small number of centers to serve the world. This plan has begun with the establishment of World Meteorological Centers (WMC's) in Moscow, Washington, and Melbourne. They receive and distribute conventional as well as satellite data from all over the world. In addition to the foregoing functions, the WMC's will prepare analyses of prevailing weather conditions and prognosis. They can also promote research and training and serve as archives for the quantities of data passing through them.

A system of Regional Meteorological Centers (RMC's) will provide a link between world and national centers. The practical responsibilities of the RMC's will vary with the countries they serve and the physical and climatic characteristics of the region. In spite of this probable variety of responsibilities, raw data for the whole of the hemisphere in which the RMC is located is likely to be channelled through it. It will work in close association with the NMC's in their sphere of operation, by providing them with the material they need and by serving as centers through which incoming observations are fed to the world centers.

Planning a world system of the kind described is a task of great magnitude and complexity. In order to ensure the orderly and systematic development of the plans, the work has been divided into three phases. Phase one, which concerned the establishment of the broad lines of World Weather Watch, was completed in the middle of 1965. Phase two calls for the preparation of a world plan in a more or less complete form and will be finished in 1966. Phase three involves the completion in full detail of the plan which must be ready for submission to the representatives of the countries of the world at the Fifth World Meteorological Congress in 1967.

d. Global Network Configurations

In a study conducted for the United States Weather Bureau,[1] Radio Corporation of America described several alternative worldwide observation, communication, and processing subsystem configurations in terms of both cost and performance criteria. With a goal of 600-nautical-mile grid coverage throughout, RCA established the following configurations.

Configuration I includes 189 ocean station vessels and 15 continental upper-air stations. At the continental stations, in addition to the standard synoptic surface observations, rawinsondes will provide vertical profiles of pressure, temperature, humidity, and wind up to 10 millibars (approximately 20 miles altitude). No significant developments are required for this system configuration and the coverage provided therein could be expanded quite rapidly. The major problem involved in Configuration I is the assignment of responsibility for maintaining the OSV's in international waters. A formula would have to be found to fix this responsibility on a continuous basis.

Configuration II utilizes merchant ships for most of the ocean observations. Thirty-nine ocean station vessels cover areas in which

[1] Radio Corporation of America, Cwb-11014, World Weather Watch Cost/Performance Analysis Study, 15 May 1966

shipping routes are infrequent. As in Configuration I, 15 continental upper-air stations will provide the land-based observations with 200 to 400 merchant ships (600- or 300-mile grid coverage) providing sea coverage in addition to the OSV's. No technological barriers exist to impede the implementation of Configuration II. However, funds should be allotted for a ship traffic analysis so that system costs are minimized.

The third Configuration proposed utilizes merchant ships, OSV's, and land stations in a similar manner as Configuration II, but horizontal sounding balloons (HSB's) are deployed at three levels. A low-level sounding system would replace the conventional rawinsonde system. To cover 400 grid points, 520 HSB's would be needed at each of the three levels; thus, a total of 1,560 HSB's would be needed in the system at all times. This configuration further assumes that the HSB observations will be collected by satellites. Balloon safety with respect to air traffic is currently being studied.

Configuration IV implements a global observation system utilizing new technology. All upper-air data will be obtained from HSB's deployed at five levels. Two of these are below 600 mb. and three above 600 mb. Included are 3,160 or 3,960 HSB's,[1] 200 or 400 merchant ships, 26 buoy stations, and 15 automatic land stations. Associated with the idea of utilizing numerous HSB's is the problem of maintaining their required distribution. Consequently, the system would have to be monitored continuously.

Along with the four configurations for a worldwide observation network, RCA proposed a communications subsystem utilizing the concepts set forth in the World Weather Watch of three World Meteorological Centers, Regional Telecommunication Hubs (RTH's), and National Meteorological Centers. Data collected from merchant vessels at sea, OSV's, and surface land stations would be sent to collection centers and relayed to NMC's. The NMC's would, in turn, transmit

[1] The number of HSB's depends upon the clustering factor used.

the collected data to RTH's to be relayed on the WMC's. The WMC's would also exchange data. The collected data would be edited, properly formatted, and checked for error at the RTH's or WMC's before being distributed. This processed data would be distributed to all nations in a standard code agreed on by the World Meteorological Organization.

Linking this communication subsystem with low-altitude satellite data collection, RCA derived a 3-satellite and a 5-satellite configuration. Most important to the successful operation of low-level satellites is the timing of interrogation and readout.

As an alternative to the low-level satellite data collection, RCA proposed the use of a synchronous satellite system for both data collection and distribution. It was found to be the "alternative providing both the greatest performance capability as well as the lowest cost in the system utilizing synchronous satellites for both collection and distribution."[1] Costs associated with the various subsystems are presented in subsection E.

3. Satisfaction of Commercial Aviation Needs

The planned systems are adequate to satisfy the previously expressed needs of commercial aviation. The FAA teletypewriter circuits, together with the worldwide circuits, will provide the necessary rapid communications.

Improvement is sought in aviation weather communications, measuring devices, processing and forecasting, and methods of presenting appropriate weather information to controllers and pilots. In addition, efforts toward improving terminal weather forecasting are expected to continue through 1971. Computerized forecast techniques will be developed for predicting ceiling, visibility, and wind velocity.

The satellite program, and the increase in horizontal sounding balloons, radiosondes, and dropsondes provided in the World Weather

[1] Radio Corporation of America, Cwb-10014, World Weather Watch Cost/Performance Analysis Study, p. IV-62

Watch System will have the capability to provide upper-air observations which are adequate both in number and in geographical distribution.

The provision of research facilities at the Regional Meteorological Centers and the growing awareness of future aviation requirements offer excellent opportunity for development of techniques to most efficiently and adequately record, transmit and analyze meteorological data.

E. Required Modifications and Related Costs

The U.S. Weather Bureau developed estimates for the Department of Commerce for a meteorological support system adequate for SST operations. Several ad hoc estimates, based on the best information available, had to be employed because of a time constraint at the time the estimates were prepared. These estimates are based on the requirements in Exhibit 24. Costs are summarized below:

1. The cost of providing a typical 2,400-mile oceanic route with six ocean station vessels[1] to cover 300 miles to either side of the route with 600-mile grid spacing would be:

Floating Operations of Stations:	6 x 3,000,000	= $18,000,000
Observing, Expendables, etc.:	6 x 300,000	= $ 1,800,000
Total Annual Operating Cost		$19,800,000[2]
Cost per Route-Mile:	$\frac{19,800,000}{2,400}$	= $8,250/year

2. The cost of adding upper-air meteorological stations to satisfy requirements for enroute accuracy of temperature and wind data would be:

[1] Each ocean station vessel consists of three ships.

[2] Estimated data on number of Coast Guard support cutter vessels for the ocean station vessels and their costs have not been confirmed by the Coast Guard.

Capital (Building and Equipment)	$200,000/station
Operating Costs	
Personal Services	$ 80,000/station/yr.
Expendable Supplies	$110,000/station/yr.
Maintenance and Depreciation	$ 20,000/station/yr.
Total Operating Cost:	$210,000/station/yr.

3. Costs for terminal weather where radar is not available would be:

Capital	
Surface Instruments	$ 20,000/station
Radar	$250,000/station
Total:	$270,000/station
Operating Costs	
Personnel	$ 80,000/station/yr.
Maintenance and Depreciation	$ 27,000/station/yr.
Communications	$ 2,000/station/yr.
Total:	$109,000/station/yr.

4. The provision of computer time for forecasting purposes would cost:[1]

Operating Cost	
Computer Time for Chart Analysis	$100,000/year
Oceanic Cable Costs (rental, personnel, and computer time)	108,000/year
Total	$208,000/year

[1] Readjusting the duties of existing personnel is assumed to eliminate the need for additional employees. No increased cost for personnel is included.

The above costs are summarized as follows:

Capital	
Ocean Station Vessels	$15,000,000/vessel
Observing Equipment (Land Stations)	200,000/station
Observing Equipment (Terminal)	270,000/terminal
Annual Operating Costs	
Terminal Observations	109,000/station
Enroute Observations (Land Stations)	210,000/station
Enroute Observations (Ocean Stations)	8,250/ocean route mile
Forecasting Services	208,000

As a follow-up to its original estimates, the Weather Bureau submitted a second, alternative set of costs. These costs comprised "the most promising alternative" to the first (extremely high) figures that resulted from the original estimates. The second estimates, enumerated below, are based on the utilization of airborne meteorological data recorders capable of direct interrogation from the ground, together with increased emphasis on the gathering of higher and more accurate data from existing land-based upper-air stations around the world.

A minimum number of ocean station vessels report from the truly data-sparse areas such as the tropical Atlantic, where data from a single route could not be expected to provide sufficient area coverage to make accurate forecasts for succeeding flights.

The following costs are based on the assumption that forecasted accuracies of $\pm$ 5°C to one standard deviation will meet the meteorological requirement for support to SST operation. The Weather Bureau recommended verification of this assumption before any use of this data. It was recommended that such a verification consist of an evaluation by SST aircraft designers and a separate evaluation by Weather Bureau

analysts and forecasting personnel regarding their ability to meet such a requirement with the data described.

The gross worldwide cost estimates follow.

Capital		
Data Acquisition		
Airborne Data Systems	($100,000 each for 200 aircraft)	$ 20,000,000
OSV's in Data Sparse	($30,000,000 each for 6 OSV's)	180,000,000
Improved Terminal Weather Data	$270,000 each for 30 airports	8,100,000
Total		$208,100,000
Increased Operating Costs:		
Data Acquisition		
Operation of Capitalized Equipment		$ 8,000,000
Increased Frequency and Accuracy from Current Stations		4,000,000
Data Processing and Dissemination		
Computer Rental		$ 100,000
Communications Cost		125,000
Personnel Costs		100,000
Total		$ 12,325,000

- In addition to the 3 climatological studies[1] already prepared by the Weather Bureau, at least 10 more are estimated to be required, at a cost of $500,000. Most urgent would be a study of the equatorial regions and one or more studies of the conditions from the equator to the pole.

- A joint UK-US-French effort was suggested at a cost of $10,000,000 over a 2-year period to include upper-air balloon observations, radar coverage, and actual research flights data collection in equatorial and tropical regions.

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[1] U.S. Department of Commerce, Weather Bureau, Climatological Summaries from SST, New York-Paris, New York-San Francisco, and San Francisco-Thule-Stockholm, July 1964

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EXHIBIT 24 - METEOROLOGICAL DATA USED AS INPUT FOR COST ESTIMATES

Flight Phase and Parameter	Observed Data		Forecast		Remarks
	Accuracy	Frequency	Accuracy	Frequency	
1. Departure					
a. Runway temperature	$\pm 1^{o}C$	Flight	$\pm 2^{o}C$	0-4 hours	Mean along the runway.
b. Surface wind	$\pm 10^{o}$; ± 2 kt	Flight	$\pm 20^{o}$; ± 5 kt	0-4 hours	Mean along the critical portion of takeoff path.
c. Gusts (cross-wind component)	± 2 kt	Flight	± 5 kt	0-4 hours	Highest value with 10% or greater probability of occurence.
d. Severe weather	--	Occur-rence	--	0-4 hours	Icing, hail, thunder-storm, etc.
2. Climb					
a. Mean air density, sur-face to tropopause	--	6 hours	--	0-4 hours	Along flight path, maxi-mum 100-mile radius of station.
b. Precipitation	--	Occur-rence	--	0-4 hours	Vertical and areal ex-tent, 100-mile radius of station.
c. Temperature at tropopause	$\pm 1^{o}C$	6 hours	$\pm 2^{o}C$	0-4 hours	
d. Height of tropopause	± 200 ft	6 hours	$\pm 1000'$	0-4 hours	

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EXHIBIT 24 (Continued)

Flight Phase and Parameter	Observed Data		Forecast		Remarks
	Accuracy	Frequency	Accuracy	Frequency	
e. Tops of clouds > 15,000 ft	±500 ft	Flight	±1000'	0-4 hours	Within 100-mile radius of station.
f. Severe weather.	--	Occurrence	--	0-4 hours	Turbulence, icing, hail, etc.
3. Cruise					
a. Temperature by route segment > 500 miles	±1°C	6 hours	±2°C	0-4 hours	Mean value for the segment; will be interpolated from "spot" measurements.
b. Wind by route segment	±20°; ±10 kt	6 hours	±20°; ±10 kt	0-4 hours	Mean value for the segment; will be interpolated from "spot" measurements.
c. Turbulence	--	Occurrence Enroute	Area of expectancy	0-4 hours	Must rely on pilot reports plus meteorological analysis of probable area extent.
d. Tops of storms	--	Occurrence Enroute	Area of expectancy	0-4 hours	Must rely on pilot reports plus meteorological analysis of probable area extent.
4. Descent and Land					
a. Runway temperature	±1°C	Flight	±2°C	0-2 hours	Mean temperature along runway.

EXHIBIT 24 (Continued)

Flight Phase and Parameter	Observed Data		Forecast		Remarks
	Accuracy	Frequency	Accuracy	Frequency	
b. Surface wind	$\pm 10^{\circ}C$; ± 2 kt	Flight	$\pm 20^{\circ}C$; ± 5 kt	0-2 hours	Mean along critical portion of landing path.
c. Gusts (cross-wind component)	± 2 kt	Flight	± 5 kt	0-2 hours	Highest value with 10% or greater probability of occurrence.
d. Precipitation	--	Occurrence	--	0-2 hours	Vertical and area extend within 100-mile radius of station.
e. Tops of clouds > 15,000 ft	--	Occurrence	--	0-2 hours	Within 100-mile radius of station.
f. Severe weather	--	Occurrence	--	0-2 hours	Turbulence, icing, hail, etc.

Source: (a) Weather Bureau Report to Department of Commerce.

- Additional high-level turbulence research flights were suggested to supplement the Wright Patterson Air Force flights. Costs could approach $500,000 over the next 5 years.
- Theoretical temperature-density discontinuities studies should be undertaken during the next 3-5 years. Such studies might cost $500,000.

The establishment of the AFTN switch and the implementation of the National Modernized Weather Teletypewriter Communications System should cost approximately $6.4 million.

The establishment cost of a centralized AFTN switch at Kansas City is estimated at $1.95 million. In addition to providing operational benefits, consolidated switching will permit a net annual savings of $436,740 resulting from reduction of 72 positions and discontinuance of existing leased equipment. There will be a concomitant reduction in administrative, management, and housing problems.

A comparison of annual operating costs for the four existing systems versus the planned consolidated AFTN system is as follows:

Location	Present System	Planned System
New York	$ 324,000	-
Miami	441,280	-
San Juan	175,600	-
Balboa	243,860	-
Kansas City	-	$300,000
Cable/Landline costs	213,832	661,092
	$1,397,832	$961,092
Annual savings from Consolidated Switch		$436,740

Exhibits 25 through 31 specify the costs associated with the various RCA communications configurations described in subsection D.2.d. To complete their cost/performance analysis, RCA combined the four observation configurations with the two communication configurations, presenting six proposed worldwide systems. A graphic presentation of the characteristics of each of the observation and communication systems is found in Exhibit 30. The annual and development costs associated with these

EXHIBIT 25 - OBSERVATION CONFIGURATION I COSTS[1]

Long-Term Equipment	
15 Continental Upper-Air Observation Station at $88[2]	1,320
189 Ocean Station Vessels at $96	18,144
Total	19,464
Annual System Costs (2 observations/day)	
Ocean Station Vessels	
Annual Cost Per Ship	1,188
System Cost (189 ships)	224,456
Continental Upper-Air Observation Station	
Annual Costs	
Inhabited Area	114
Remote Area	153
System Cost	1,904
Total	226,360

Notes: (1) Costs are in thousands of dollars.

(2) There are 10 stations in inhabited areas, and 5 stations in remote areas. Coverage by upper-air stations in U.S. is adequate, so the proposed additional stations would be outside continental U.S.

EXHIBIT 26 - OBSERVATION CONFIGURATION II COSTS[1]

Long-Term Equipment	
15 Continental Upper-Air Observation Stations at $88	1,320
39 Ocean Station Vessels at $96	3,744
200 to 400 Ships at $96	19,200 - 38,400
Total	24,264 - 43,464
Annual System Costs (2 observations/day)	
Moving Ships with Rawinsonde	127
Annual Cost Per Ship	127
System Cost (200 Ships)	25,460
(400 Ships)	50,920
Ocean Station Vessels	
Annual Cost Per Ship	1,188
System Cost	46,316
Continental Upper-Air Observation Stations	
System Cost	1,904
Total Annual System Cost (200 Ships)	73,680
(400 Ships)	99,140
Development Costs	
Ship Traffic Analysis	125

Note: (1) Costs are in thousands of dollars.

EXHIBIT 27 - OBSERVATION CONFIGURATION III COSTS[1]

Long-Term Equipment	
15 Continental Upper-Air Stations at $68	1,020
39 Ocean Station Vessels at $61	2,379
200 to 400 Merchant Ships at $61	12,200 to 24,400
25 to 50 HSB Launch Sites at $22	550 to 1,100
Total	16,149 to 28,899
Annual System Costs (2 observations/day)	
Merchant Ships with Low-Level Sondes	
Annual Cost Per Ship	80
System Costs (200 Ships)	16,000
(400 Ships)	32,000
Ocean Station Vessels	
System Costs	46,316
Continental Upper-Air Stations Low-Level Sondes	
System Costs	1,410
Buoys	
Unit Cost (Deployed)	27
52 Buoys Per Year	1,399
Horizontal Sounding Balloons	
Unit Cost	1,800 to 2,800
6-Month Life at $310 Per Year	5,616 to 8,736
3-Month Life at $6,240 Per Year	11,232 to 17,427

EXHIBIT 27 - (Continued)

Total Annual System Costs (2 observations/day)

	Long-Life HSB's	Short-Life HSB's
200 Ships/OSV's	69,343 - 72,063	74,959 - 81,199
400 Ships/OSV's	85,343 - 88,463	90,959 - 97,199
200 Ships/Buoys	24,425 - 27,545	30,041 - 36,281
400 Ships/Buoys	40,425 - 43,545	46,041 - 52,281

Development Costs

Horizontal Sounding Balloons	6,050
Low-Level Sonde	300
Subtotal	6,350
Buoy(s)	2,200
Total	8,550

Note: (1) Costs are in thousands of dollars.

EXHIBIT 28 - OBSERVATION CONFIGURATION IV COSTS[1]

Long-Term Equipment	
25 to 50 HSB Launch Stations	550 to 1,100
200 to 400 Merchant Ships	1,800 to 3,600
Total	2,350 to 4,700
Annual System Costs	
Horizontal Sounding Balloons	
High-Level Balloons	
Unit Cost	1.8 to 2.8
System Cost (6-mo. life)	5,616 to 8,736
System Cost (3-mo. life)	11,232 to 17,472
Low-Level Balloons	
Unit Cost	1.6 to 2.6
System Cost (2-wk. life)	66,560 to 108,160
System Cost (4-wk. life)	49,920 to 81,120
Buoys	
Total System Cost (52 per Year)	1,398
Cost for 126 Buoy Stations (252 Buoys per Year)	
Unit Cost (Deployed)	23.4
System Cost	5,897
Automatic Land Stations	
Unit Cost (Deployed)	26.3
System Cost	394.5
Merchant Ships, Surface Observations	
Unit Cost	4
System Cost (200 Ships)	800
(400 Ships)	1,600

EXHIBIT 28 (Continued)

Total System Costs		
	Long-Life, Low-Level HSB's	
200 Ships	58.1 to 92.4	63.7 to 101.2
400 Ships	58.9 to 93.2	64.5 to 102.0
Buoys	61.8 to 96.1	67.4 to 104.9
	Short-Life, Low-Level HSB's(2)	
200 Ships	74.8 to 119.5	80.4 to 128.2
400 Ships	75.6 to 120.3	81.2 to 129.0
Buoys	78.5 to 123.2	84.1 to 131.9
Development Costs		
HSB's		6,050
Buoys		2,200
Automatic Land Stations		450
Shipboard Surface Observation Equipment		50
	Total	8,750

Notes: (1) Costs are in thousands of dollars.

(2) If 25 to 50 HSB launch sites are assumed, and are located in remote areas, additional annual cost is $700 to $1,400.

EXHIBIT 29 - ANNUAL COSTS FOR COMMUNICATIONS SUBSYSTEM ALTERNATIVES

Subsystem Configuration	Annual Cost (1)	
	Observation Configuration I or II	Observation Configuration III or IV
Synchronous Satellites Only (Distribution to NMC's)	8.7 to 12.2	10.5 to 14.1
Conventional Communications Only	19.0 to 32.0	Not Applicable
Synchronous Satellites (Collection and Distribution to RTH's) and Conventional Communications (Distribution from RTH's to NMC's)	20.3 to 28.0	22.0 to 29.8
Conventional Communications and Low-Altitude Satellites (for Collection)	24.3 to 56.2 (2)	24.3 to 56.2

Notes: (1) Costs are in millions of dollars.

(2) Same capability assumed for all observation configurations.

EXHIBIT 30 - CHARACTERISTICS OF THE OBSERVATION AND COMMUNICATION SYSTEMS

Observation Configurations		Communication Configurations
Configuration I	New Stations 189 OSV's(1) 15 Continental Upper-Air Stations	Conventional: (Leased Commercial and Govt. Facilities)
Configuration II	Utilize 200-400 Merchant Ships New Stations 39 OSV's(1) 15 Continental Upper-Air Stations	Synchronous Satellites: (Four Provide Data Collection and Distribution)
Configuration III	Utilize 200-400 Merchant Ships New Stations 39 OSV's(1) 15 Continental Upper-Air Stations(2) 1,560 HSB's(3) in Flight at Any One Time	
Configuration IV	Utilize 200-400 Merchant Ships 3,160 or 3,960 HSB's(4) 26 Buoy Stations 15 Automatic Land Stations	

Notes: (1) Ocean Station Vessels.

(2) Coverage up to 600 mb. only with low-level sondes above 600 mb. HSB's provide the upper-air data.

(3) Horizontal sounding balloons.

(4) All upper-air observations provided by five levels of HSB's.

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EXHIBIT 31 - WORLDWIDE METEOROLOGICAL SYSTEMS COSTS

Worldwide System Observation	and Communication	Annual Cost: Observation	Annual Cost: Communication	Investment: Implementation	Investment: Development	Total Annual Cost	Total Investment
Config. I	Conventional	226	21-27	19.5	--	247-253	19.5
Config. I	Synchronous Satellites	226	9-12	61.7	5.2-8.0	235-238	66.9-69.7
Config. II	Conventional	200 ships 74 400 ships 99	22-28 26-32	24.3 43.5	.13	96-102 125-131	24.43 43.63
Config. II	Synchronous Satellites	200 ships 74 400 ships 99	9-12 9-12	66.5 85.7	5.3 8.1	83-86 108-111	71.8 93.8
Config. III	Synchronous Satellites	200 ships 69-81 400 ships 85-97	11-14 11-14	58.3 71.1	13.8 16.1	80-95 96-111	72.1 87.7
Config. IV	Synchronous Satellites	4-wk. HSB life 58-102 2-wk. HSB life 75-129	11-14 11-14	44.6 46.9	14.0 16.8	69-116 86-143	58.6 63.7

Note: (1) Costs are in millions of dollars.

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worldwide systems are set forth in Exhibit 31. Information presented in these exhibits was derived from RCA's World Weather Watch Cost/ Performance Analysis Study of May 1966.

VIII. RADIATION MONITORING

A. Requirements of Commercial Aviation through 1975

Introduction of the Concorde and the SST into scheduled commercial aviation service by 1975 will necessitate the development and implementation of radiation forecasting, detection, warning, and measuring systems prior to the aircrafts' respective scheduled commercial operation dates, 1971 and 1974. This development is necessary because of expressed potential radiation hazards at the Concorde and SST cruising altitudes of 50,000 to 80,000 feet.

On the basis of present estimates of expected radiation levels at these altitudes, safety considerations indicate the need for adequate warning systems to prevent unnecessary radiation exposure to passengers and crew. Through 1975, commercial aviation requires a national space environment monitoring and forecasting system which can provide daily radiation information and forecasts as a routine operation, and a pilot advisory warning service to direct enroute SST's to descend to safer altitudes or to advise rescheduling of subsequent flights.

The complexity of systems to fulfill these requirements will depend in part on the developments in the next 2 to 4 years of present research efforts to define more accurately the extent and type of hazards involved and to improve high-altitude radiation forecasting techniques. The ultimate demand on these systems will be the prevention of passenger and crew exposure to radiation dosage rates in excess of those deemed safe in the guidelines established (and by that time in effect) by the Federal Radiation Council.

B. Present Systems

There is presently no operational system to continuously monitor and detect radiation levels as required to provide adequate information for the SST program. Efforts to date have primarily been research of

the radiation problem at SST altitudes in order to determine whether a hazard exists and if so, its extent; feasible monitoring, alerting, and protective systems; and a plan for implementing these systems or services.

The several government agencies which require information relative to space radiation are the Department of Commerce, Department of Defense, National Aeronautics and Space Administration, Federal Aviation Agency, and Atomic Energy Commission.

A number of individual and joint programs and activities have been undertaken by the various agencies to assist in solving their specific problems. Some of the programs and activities closely related to the scope of this study are:

- The Institute for Telecommunication Sciences and Aeronomy's (ITSA) Space Disturbance Laboratory and Forecast Center (Environmental Science Services Administration (ESSA) of the Department of Commerce) in Boulder, Colorado
- NASA's Apollo Space Radiation Warning System--seven optical observation stations and three radio observation stations spread around the world
- The U.S. Air Force Air Weather Service daily solar activities forecasting service
- Solar research and development to increase reliability and accuracy of predicting proton flares at the Air Force Sacramento Peak Observatory
- The combined 2-year USAF/FAA/NASA High-Altitude Radiation Environment Study (HARES)
- Naval Research Laboratory solar radiation satellites
- Air Force VELA satellites
- NASA Tiros and TOS satellites

1. <u>ITSA - Space Disturbance Forecast Center</u>

Now under the Environmental Science Services Administration, the Space Disturbance Forecast Center cu[illegible]as a tentative three-fold mission:

a. To determine whether space radiation is a hazard

b. If so, to indicate what services are necessary for human beings flying at very high altitudes

c. To set up necessary services.

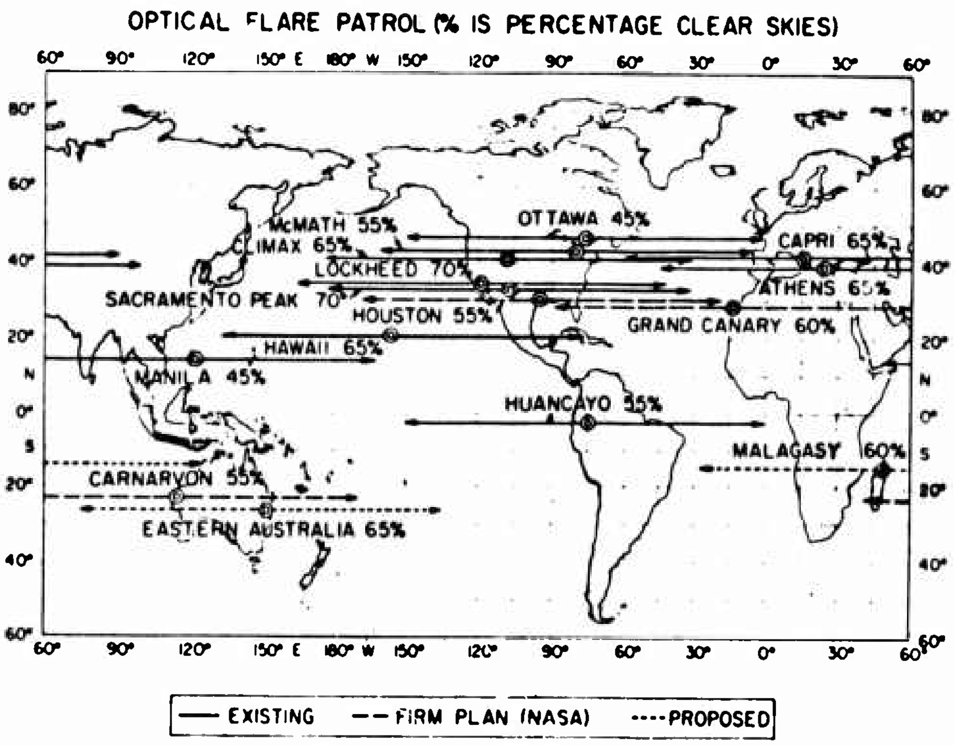
These efforts are performed in conjunction with the Air Weather Service, NASA, and FAA.

The service of providing solar radiation forecasts has been in operation for over a year and its performance accuracy has been reasonably good. This service began 24-hour operation in July, 1966. There are presently 10 Operating Optical Flare Patrol Stations, three planned (by NASA) and two proposed. Exhibit 32 shows the location of the stations and Exhibit 33 shows the percent coverage these stations will provide. Forecasting will improve with addition of these Optical Flare Patrol Ground Stations and with increased utilization of such equipments and techniques as high-altitude riometers, forward scatter very-high-frequency detectors, ground-based super neutron monitors, and solar radio observatories.

The monitoring aspect of the operation is practically the sole source of information for forecasting. As more knowledge is gained about the beginning and evolution of sun spots, forecasting techniques will be advanced and reliability improved.

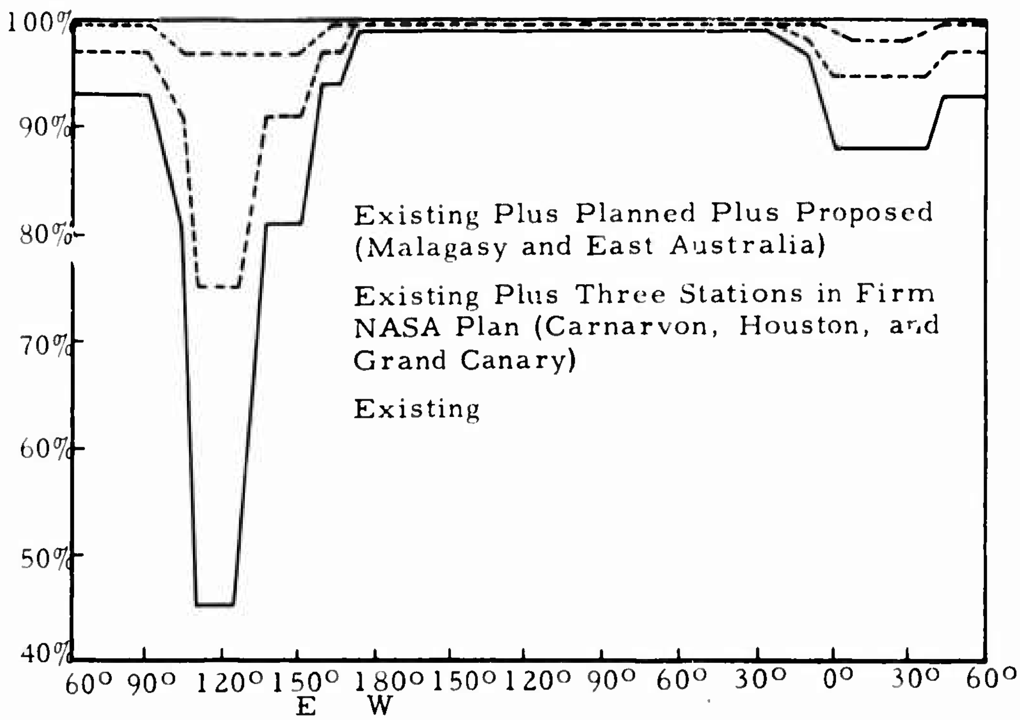
It could conceivably be as late as 1969 before enough data from the many programs have been collected and evaluated to make accurate assessments of the radiation hazard at SST altitudes. If the monitoring and forecasting service is found to be necessary, ESSA will probably provide pre-flight service (forecast, briefing), alerts or warnings of a sizable event (including electromagnetic characteristics and particle information), and an ex post facto report on the event.

Planned ESSA facilities should be adequate for forecasting flares which might necessitate grounding of an SST, warning aircraft in flight to descend to lower altitudes, and ex post facto reporting.



Source: (a) Teweles, Sidney and McInturff, Raymond M., Physical and Synoptic Meteorology in Relation to the Special Requirements of Supersonic Aircraft Operations, 30 May 1966

EXHIBIT 32- WORLDWIDE DISTRIBUTION OF OPTICAL FLARE PATROL OBSERVATORIES CAPABLE OF MONITORING AND REPORTING REAL-TIME DATA



Source: (a) Teweles, Sidney and McInturff, Raymond M., Physical and Synoptic Meteorology in Relation to the Special Requirements of Supersonic Aircraft Operations, 30 May 1966

EXHIBIT 33 - PERCENTAGE OF TIME SOLAR DISC IS OBSERVABLE BY OPTICAL FLARE PATROL

2. NASA Apollo Space Radiation Warning System

NASA is developing a worldwide solar flare monitoring system to support the manned space program. The system is designed to provide real-time data to the Manned Spacecraft Center in Houston and ESSA's Space Disturbance Forecast Center in Boulder and will consist of seven optical flare patrol stations and three radio telescope stations.

3. USAF/FAA/NASA High-Altitude Radiation Environment Study

The joint USAF/FAA/NASA High-Altitude Radiation Environment Study which began in the summer of 1966 and will terminate in July 1968 gathers appropriate data during high-altitude RB-57F flights. Some of the objectives of the program are the measurement of direct radiation doses received by human tissue, measurement of linear energy transfer, correlation of data with balloon-gathered data, and measurement of neutron and proton spectra. Results from this program will be extremely helpful in developing specifications for SST radiation instrumentation. These flights will help determine the need for systems to give dose profile, accumulated dose, and danger warning. Such data may also contribute significantly to the knowledge of the biological effects of various particles.

Since the program will be conducted through the peak of the 11-year solar cycle, it is expected that special flights will occasionally be conducted to collect data during relatively large solar flares.

The Air Force Air Weather Service Solar Forecast Center located in Colorado exchanges data on a routine basis with the ESSA Space Disturbance Forecast Center at Boulder, Colorado.

The goal of the solar research and development effort at Sacramento Peak, New Mexico is an increase in the reliability and accuracy of predicting proton flares which originate on the sun. This research includes the study of events on the sun and in space which precede solar flares. Equipment is being designed and developed to aid data reduction, to provide control systems for monitoring the events, and to develop a system for transmission of solar-flare pictures.

C. Adequacy of Present Systems

1. Stretched Subsonics

Space radiation forecasting and monitoring is not featured in flight plans for current commercial subsonic airliners because there has been no need to date for radiation services at the normal operating altitudes. The stretched subsonics (Douglas DC-8-61, 62, 63) will operate at approximately the same speeds and altitudes as present commercial aircraft. Their introduction will impose no requirements for radiation information services or warning devices of any type.

2. High-Capacity Subsonics

High-capacity subsonics (Boeing 747, Lockheed 500) will also operate within the same general parameters as present-day commercial jet aircraft. Their introduction will not impose a requirement for radiation information services or warning devices.

3. Concorde

The British-French Concorde which is expected to be the first commercial supersonic aircraft in the free world introduced into scheduled service, will cruise at altitudes high enough to cause a possible need for radiation forecasting and monitoring systems. The Concorde design includes provisions for an in-flight radiation warning meter. An experimental radiation meter has been developed to give in-flight warning of abnormal radiation situations.

The British conducted extensive investigations on galactic cosmic radiation hazards via balloon flights from Fort Churchill, Canada, during a solar minimum year (1964) and concluded that passengers and crews will be exposed to "the same low, acceptable, and safe biologically significant dose due to galactic cosmic secondary radiation whether they fly low (35,000 feet) and subsonic for 5-6 hours or high (65,000 feet) and supersonic for 2-3 hours."[1]

The British plan to fly stratospheric balloons at times when large solar flares are considered to be probable. Experiments will be

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[1] Wilson, I. J., Aldermaston, Our Work for the Concorde

conducted on radiation detectors, tissue-equivalent ionization chambers, and the linear energy transfer spectrometer.

An experimental in-flight radiation warning meter will be included in order to measure its response. Further tests of the warning meter will be carried out in 1969-70 onboard the prototype and pre-production Concordes as they undergo air-worthiness flight testing.

4. <u>SST</u>

The United States SST, the second major aircraft type designed and manufactured in the free world planned for scheduled commercial airline service, will cruise at altitudes which may be hostile because of radiation hazard. The SST is scheduled for Civil Aeronautics Board certification in 1974--approximately 3 years later than the targeted entry of the Concorde into airline fleets.

The two competing SST airframe manufacturers have devoted considerable effort to investigating the potential radiation hazard problem at altitude and to determining adequate safety measures for air crew and air travelers.

The Boeing report, <u>Some Radiation Problems in the Supersonic Environment</u>, concludes that the radiobiological problem for supersonic aircraft is not serious and that neither passengers nor crew will experience doses in excess of recommended tolerance levels[1] in normal flying schedules.

In Lockheed's <u>Horizon</u> magazine, Dr. Charles I. Barron, Medical Director for the Lockheed California Company, concludes that "the findings are most encouraging in indicating a low-level hazard, which was safely tolerated by man."[2]

Until more precise information on the biological effects of certain types of radiation is available, it cannot be said categorically

[1]The Boeing Company, Boeing D2-90391, <u>Some Radiation Problems in the Supersonic Environment</u>, Sheldon, W.R. and Dye, D.L., November, 1963

[2]Barron, Charles I., "Of Airmen Exposed to Supersonic Transport Altitudes", <u>Horizon</u>, Summer, 1965

that no hazard exists and that no forecasting, monitoring, warning and protection systems are required. Normal safety protection should be provided within the limit of reasonable cost. Even for the worst cases of radiation dose expected, however, the ground observatory network in process appears adequate to provide monitoring, warning, and protection to passengers and crew.

D. Future Systems

1. Background

a. Involvement of Federal Agencies

Various government agencies have mission-associated needs for information about potential radiation hazard at high altitudes. These agencies are the Department of Commerce, Department of Defense, National Aeronautics and Space Administration, Federal Aviation Agency, and Atomic Energy Commission.

b. SST Involvement

The panel on Space Environmental Forecasting of the Interdepartmental Committee for Atmospheric Sciences, Federal Council of Science and Technology has summarized the common needs for space radiation information which exist or are anticipated to exist. There are common needs for:

- Optical observation of solar events
- Radio observation of solar events
- Monitoring of solar X-ray emission
- Monitoring of solar proton flux
- Monitoring of trapped particle flux
- Measurements of atmospheric structure

A joint program to satisfy these needs would aid [1] the FAA in providing adequate information relative to SST flights at the high altitudes of 50,000 to 80,000 feet.

[1] Federal Council of Science and Technology, Final Report of the Panel on Space Environmental Forecasting of the Interdepartmental Committee for Atmospheric Sciences, December 1964

There has been no need to date for an operational system to forecast or continuously monitor radiation levels at SST altitudes. Normal commercial flights rarely reach an altitude over 40,000 feet, a level below which the atmosphere has effectively blocked ionizing radiation. Reconnaissance and tactical aircraft flights often exceed these altitudes, but the relatively moderate number of flights, the usually brief duration of such excursions, and number of persons exposed has not yet warranted the expense of extensive operational monitoring systems.

Neither has there been demonstrated to date a need for monitoring radiation levels at SST altitudes to protect passengers. However, unless the need for radiation monitoring systems can be thoroughly refuted on scientific and medical bases, all possible means must be exercised to obtain the data upon which such a determination can be based in order to provide maximum assurance that SST crews and passengers will be afforded adequate protection from any ambient and potential radiation hazard.

c. Identification of Problem Areas

The overall problem of radiation hazards at SST altitudes must be examined in discrete parts in order to determine the total radiation effect. The hazards of fission fragments, galactic cosmic radiation, solar radiation, and total radiation effect are discussed below.

(1) Fission Fragments

Data collected from high-altitude military flights are essentially sufficient to permit dismissal of fission fragments from past nuclear explosions as a contributing factor to the radiation hazard at SST altitudes. The residual radiation level from manmade nuclear detonations has diminished to the point that it may be ignored, and this condition will prevail unless the moratorium on upper-air nuclear testing is abrogated or violated. The remainder of this study assumes that residual radiation levels will not change to a point at which they will contribute to the potential radiation hazard. Even if fission fragments increase in number, the cabin air filtering systems on current commercial airliners can prevent the passage of excessive amounts of radioactive materials.

Thus, two primary sources of radiation remain which must be studied in depth to determine the existing and potential hazard to which SST passengers and crew may be subjected, i.e., galactic cosmic radiation and solar radiation. These two sources will be discussed separately. General background information on each type will be presented and a broad statement of present ability to identify and measure the dose level exposure to SST passengers and the concomitant damage will be made.

(2) Galactic Cosmic Radiation

Galactic cosmic radiation consists primarily of energetic protons, alpha particles, and heavier nuclei, and is derived from sources other than the sun.

The degree of biological hazard from cosmic radiation is a function of altitude, geomagnetic latitude, and solar activity. Generally speaking, the dosage from primary rays (energetic protons, alpha particles, other heavy nuclei) decreases:

- near the earth because of increased shielding of the atmosphere
- at the lower latitudes due to the lessened effect of the magnetic poles
- with increased solar activity because the dose from galactic cosmic radiation in a solar minimum year is about twice that of a solar maximum year

Aside from primary galactic cosmic radiation, nuclear interactions in the atmosphere produce secondary radiation in the form of secondary protons, neutrons, and alpha particles of low energy. This resulting scatter is sometimes called a "nuclear star." Toward the end of the star track (known as a "thin down"), local dose may be very high, although the total dose to the body would be very low. The overall biological effects of such hits are not yet fully understood. This type of radiation exposure might be most serious, for example, in the case of a newly pregnant woman.

Because of this secondary radiation effect, total dose rates due to galactic cosmic radiation are generally at a maximum at altitudes between 50,000 and 80,000 feet.

(3) Solar Radiation

The last type of radiation to be discussed which contributes to ambient radiation at SST altitudes is solar radiation. The intensity of solar radiation varies considerably and is dependent on the intensity of solar flares which emanate from sun spots. Present technology is not adequate to predict accurately the likelihood or the intensity of solar flares, though it is known that the intensity of these flares varies generally through an 11-year cycle. Doses from solar flares, added to the relatively constant intensity of galactic cosmic radiation, are the cause of most concern regarding the potential hazard of excessive radiation exposure in SST flights. As solar flares develop, solar radiation flux may change greatly.

(4) Total Radiation Effect

It is not intended to discuss here the complex process of determining or defining dose rates, but rather to identify the costs which may have to be incurred in order to give reasonable assurance that SST passengers and crews will not be subjected to radiation exposure higher than that level deemed safe by the Federal Radiation Council. This report, therefore, will state the existing recommended maximum levels of exposure and discuss the SST radiation problem in relation to these guidelines.

For the population at large, the Federal Radiation Council recommends that the maximum exposure be 0.5 rems a year[1] and that radiation workers be permitted a maximum dose of 5 rems a year. Studies to date indicate that SST crews flying 10 hours per week at 75,000 feet

[1] A rem (roentgen equivalent man) is a unit of ionizing radiation dose which consists of 1 rad (a unit of absorbed dose of ionizing radiation) multiplied by the relative biological effectiveness of the specific type of ionizing radiation under consideration.

over polar routes with no special precautions during a solar maximum year will receive ionizing radiation equal to about twice the amount allowed the general public, and yet less than that amount allowed for workers in radiation laboratories.

2. Description of Systems Planned

a. ITSA, ESSA Program

Most of the data used by the Space Disturbance Forecast Center in preparing its forecasts is furnished by existing ground observatories. Some data are received from satellites, but more advanced data interpretation techniques must be developed to improve the quality of the information. The initial operational system for space radiation detection will be comprised of ground observatories with satellite backup. By 1968-69, a TOS satellite with a proton detector should be in operation.

By the early 1970's, both geo-stationary and orbiting satellites which can monitor radiation levels and relay the information to the Space Disturbance Forecast Center may be in operation. By 1973, the Center will probably depend on satellites as the primary source of data, and use the ground observatories as a backup system. The Center would then disseminate the appropriate data to the requesting groups on a continuous schedule or as the frequency and severity of solar events dictates. The most energentic particles would probably be detected by ground neutron monitors.

It is expected that the information available from the forecast center will satisfy the radiation monitoring requirements for Concorde and SST flights. This information will be available without a separate and distinct system designed solely to meet the requirements of the SST. Within the next year, the Center expects to expend about half of a man-year to investigate satisfaction of SST requirements for forecast, warning, and reporting services.

b. NASA Apollo Space Radiation Warning System

The addition of the three planned and two proposed ground observatories to the existing NASA Apollo Space Radiation

Warning System (as shown in Exhibits 32 and 33) will provide almost 100 percent assurance of worldwide coverage for the monitoring of solar flares. The existing observatories of this system are already in use as part of the national space environment forecasting effort.

In order to be fully effective, these observatories would have to be manned on a continuous basis, rather than just during Apollo missions. They should have the capability to make immediate reports of large flares and daily reports of small flares, and to provide data on solar observations to the scientific community according to a reasonable schedule. The inclusion of the solar radio observatories in this worldwide network will contribute to its effectiveness.

The total NASA operational system will consist of seven solar optical observatories and three solar radio observatories. The radio observatories will give 100 percent worldwide coverage and the optical observatories will give about 98 percent coverage. ESSA currently provides people to man these sites on a continuous basis. There is close coordination between NASA and ESSA on the program.

Equipment and installation costs for the sites can be broken down to: radio telescope--$100,000, optical telescope--$50,000, and average site installation--$100,000. Operating costs will be approximately $60,000 per year per site.

c. U.S. Air Force Programs

The Air Force Air Weather Service operates a daily solar forecasting service which furnishes a summary of present solar activity, a forecast of solar flares and proton events, and descriptions of present and forecast solar radio flux and geomagnetic activity. Programs have been undertaken to improve solar forecasting techniques.

Basic studies of the sun and its radiations will be carried out at the Sacramento Peak Observatory in New Mexico. These studies will contribute to man's knowledge of space radiation and ultimately to a better understanding of the radiation hazard associated with high-altitude aircraft flights.

d. High-Altitude Radiation Environment Study

The joint AF/FAA/NASA High-Altitude Radiation Environment Study began in the summer of 1966. The Air Force role is to provide operational support to collection of radiation data for FAA and NASA. The FAA is investigating direct dose received by human tissue and linear energy transfer, and is correlating data received on test flights with other data collected (balloons, etc.). NASA's primary effort is the collection of data on neutron and proton spectra.

An interim report on the study which closes in July 1968 will be presented in July 1967. The data received should help to consolidate opinions on the extent of the radiation hazard well before scheduled flight operation of either the Concorde or the SST, and should significantly aid the determination of radiation detection instrumentation needed onboard the aircraft.

e. Onboard Radiation Monitoring Systems

In addition to the ground support systems which aid high-altitude aircraft in radiation detection, there will be airborne equipment to warn when a threshold dose rate is approached, thus alerting the pilot to descend to a safe altitude. Present plans demand that both the Concorde and SST be equipped with such warning systems.

It is also possible that crew members of high-altitude commercial aircraft will be required to wear radiation film badges during flights in order that an accurate record may be kept of individual cumulative exposure over a period of time. This determination would be made by the AEC after an assessment of the radiation hazard to which crew members would be exposed. The film badge service would necessitate no initial investment, since it is normally available on a rental basis from various radiation services companies.

Other types of radiation monitoring equipment may be installed on these aircraft as a result of the findings of the High-Altitude Radiation Environment Study. Onboard systems should be able to provide danger warning, accumulated dose (if it is significantly great), and dose profile. Interchangeable systems may have been developed for the Concorde and the SST by the time both aircraft are operational.

3. Conceptual Systems

a. Satellite Warning System

By the mid-1970's, solar radiation detection and monitoring systems onboard satellites will probably have replaced ground observatories as the primary solar radiation data source. The ground optical radio observatory network will probably continue to operate as a supplement to the satellite system.

b. Ground-Based Neutron Monitors

A worldwide network of highly sensitive neutron monitors is needed to detect moderately hard solar events,[1] because hard events cause increases in ground-level neutron count. This network would help to provide necessary monitoring services for the SST.

c. Nerve Center for Radiation Forecast and Warning Systems[2]

Rapid notification of the imminent onset of a solar flare is of utmost importance if the information is to be useful to an SST. A national or international nerve center for systematic data dissemination would be necessary to assure real-time aircraft alerts based upon satellite or ground observatory information. Such a center would correlate data received from participating agencies and disseminate appropriate announcements to all requesting and using organizations. Such a nerve center would reduce communication requirements and eliminate the need for redundant programs and systems.

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[1]A hard solar event is an event in which the energy levels of the particles in the solar flare are approximately 200 MEV (million electron volts) or greater.

[2]SC/AMS Panel on Meteorological Problems of Supersonic Aircraft, Initial Statement of Requirements for Additional Meteorological Services Specifically Designed to Support Supersonic Aircraft (Panel Report No. 2), 20 December 1965

Many other programs are in progress and planned which will contribute to increased knowledge of the upper-atmosphere radiation environment. None of the costs of these programs can be attributed to SST requirements, but the knowledge gained from them will be of benefit to SST high-altitude operations. Some of the programs and their operational objectives are:

(1) Air Force satellites to identify the types and energies of solar radiation. Two satellites are scheduled to be launched by the end of 1968.

(2) National Science Foundation programs to monitor the effects of solar activity. These activities "....will continue in modified form in the next few years, and among other things, will contribute to the eventual improvement of the forecasting abilities of the mission-oriented agencies."[1]

4. Satisfaction of Commercial Aviation Needs

As stated previously, commercial aviation does not require radiation systems prior to the introduction of the first aircraft scheduled to cruise at altitudes above 40,000 feet. The numerous investigations sponsored by several government agencies are increasing knowledge of the radiation environment at high altitudes and are contributing to the subsequent development of systems adequate to permit routine use of this space for commercial aviation. Even with the conclusions reached by scientists as to maximum expected dose rates based on relatively conservative and pessimistic assumptions, the future radiation systems expected to operate before the first scheduled high-altitude commercial flights seem adequate to prevent undue radiation exposure to passengers and crews.

[1] Federal Council of Science and Technology, Final Report of the Panel on Space Environment Forecasting of the Interdepartmental Committee for Atmospheric Sciences, December 1964

High-altitude flights would probably not be affected more than three or four times a year, and then only during one or two solar maximum years. The consequences would be to reroute flights to lower cruising altitudes or to reschedule flights during the brief periods of maximum solar activity. The periods of solar activity affecting high-altitude flight plans would last no more than several hours each, and each event could be detected and observed by onboard radiation warning systems as well as ground observatories.

E. Required Modifications and Related Costs

The worldwide radiation detection and warning system scheduled for operation by 1974 will adequately meet SST requirements for support of the radiation warning system onboard the aircraft. This worldwide system is being financed by NASA and will require no capital outlays to permit use of the data for SST flight planning.

Many programs and systems, however, may ultimately contribute to increased understanding and better definition of the high-altitude radiation hazard as well as to refinements and improvements in radition detection and forecasting techniques. Some of these programs or systems and their estimated costs are listed below:

NASA Apollo Space Radiation Warning System (10 stations)	
Procurement and Construction	$1,650,000
Annual Operation and Maintenance at $60,000/station	600,000
HARES Program	
FAA Instrumentation	100,000
FAA Data Reduction (3 years)	50,000
SST Airborne Radiation Detection Equipment/Aircraft	
Dose Profile	5,000
Accumulated Dose	2,000
Danger Warning (may have to measure LET)	Not yet available

NASA Balloon Flights	$ 350,000/yr.
Continuing NASA Space Radiation Studies from the Office of Advanced Research and Technology	Indeterminate
Solar Proton Monitors on TOS Satellite (2 years of continuous observation)	300,000
Riometers (Proton Bombardment Detection) (-ESSA has about 12 in operation)	20,000 ea.
VHF Forward Scatter (three links now in Arctic, three in Antarctic)	20,000/link

In addition, ESSA is developing a satellite plan to satisfy its future needs in space disturbance detection and forecasting. The plan is scheduled to be fully developed before the end of 1967.

IX. MODIFICATIONS TO ENROUTE SUPPORT SERVICES AND RELATED COST ESTIMATES

EXHIBIT 34 - ENROUTE SUPPORT SERVICES MODIFICATION COSTS SUMMARY (TIME-PHASED)[1]

	1966-1973	1974-1975	1976-1990	Total
Airways, Navigation and Communications	0	0	0	0
Meteorology (begin 1970)	421[3]	222	1,665	2,308
Radiation (begin 1967)	5.6[3]	1.2	9	15.8
Total	426.6[3]	223.2	1,674	2,323.8

Notes: (1) Costs are in millions of dollars.

(2) Requirements for these systems are not imposed by commercial aviation.

(3) A rule-of-thumb has been applied stating that the first two years' O&M costs are approximately equivalent to one year's normal O&M costs.

[redacted]

EXHIBIT 35 - ENROUTE SUPPORT SERVICES MODIFICATION COSTS SUMMARY (BY AIRCRAFT-TYPE)(1)

	Current	High-Capacity Aircraft				
		Subsonic		Supersonic		
	Normal Planning	DC-8-63	B-747	Concorde	SST	Total
Airways, Navigation and Communications	-	0	0	0	0	0
Meteorology						
Investment	88	0	0	0	0	88
Annual Operational and Maintenance	111	0	0	0	0	N/A
Radiation						-
Investment	1.7	0	0	0	0	1.7
Annual Operational and Maintenance	.6	0	0	0	0	N/A
Totals (minus Operational and Maintenance)	89.7	0	0	0	0	89.7

Notes: (1) Costs are in millions of dollars.
(2) Requirements for these systems are not imposed by commercial aviation.

[redacted]

X. CONCLUSIONS

Thorough examination of the economic implications of an SST on enroute support services has resulted in the following conclusions:

1. The SST will impose no significant unique requirements on airways, navigation and communications systems. Operational requirements imposed upon the SST designers dictate that the SST will perform within the limitations and capabilities of the air traffic control system programmed to be in operation. SST avionics will incorporate highly accurate onboard inertial navigation systems thereby negating the need for more sophisticated externally dependent navigational aids. No unique SST costs are identifiable.

2. Although meteorological systems improvements are not operational necessities, they are highly desirable for reasons of improved safety and economy. While the experience of supersonic military aircraft at SST altitudes has established that current meteorological technology is adequate to permit safe, programmed operations above 40,000 feet without undue risk to aircrew members, inauguration of scheduled, commercial, supersonic service will--for reasons of passenger confidence and operational and economic efficiency--impose requirements for an improved meteorological forecasting capability. There will be a need for better terminal area forecasts, more complete high-altitude data on such phenomena as temperature, turbulence, jet streams, wind shear, and particulate matter, and more rapid communication of meteorological data.

Indeed there presently exists the desirability for these flight planning and operating improvements. Study and research into these aspects are being intensively pursued, and systems to alleviate existing deficiencies in these areas should be operational prior to the first scheduled

commercial flights of the Concorde. Therefore, their costs would not be primarily attributable to high-altitude supersonic commercial aviation needs.

3. The extent and exact nature of the radiation hazard at SST cruising altitudes is yet to be determined. Current knowledge indicates a need for both onboard radiation warning systems and ground-based solar observatories. The warning system is considered a necessary and integral part of the aircraft. The cost of the installation of ground-based solar observatories is being borne completely by NASA as part of the Apollo Space Program and is expected to fulfill SST requirements. No unique SST costs can be identified.

XI. RECOMMENDATIONS

Aside from the conclusions which have been drawn as a result of this study of the enroute support services, there are certain recommendations which can be made. These recommendations are intended to be primarily reinforcements to planned programs which conceivably could be delayed to the point that their contributions to optimum enroute support systems for the SST might occur later than is desirable.

A. Worldwide Meteorological Network

The establishment of a worldwide meteorological network is recommended as a means of improving the efficiency and safety of worldwide SST operations. Accurate and current preflight forecasting and enroute weather information would also contribute to flight economy. Present efforts should be continued at a pace that can ensure achievement of an operational worldwide network prior to scheduled commercial supersonic flights.

B. High-Altitude Radiation Research

Research should be continued in the fields of solar flare forecasting and determination of biological effects of certain high-altitude radiation components so that more realistic solar flare avoidance procedures may be developed and better definition of radiation dosage guidelines established.

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